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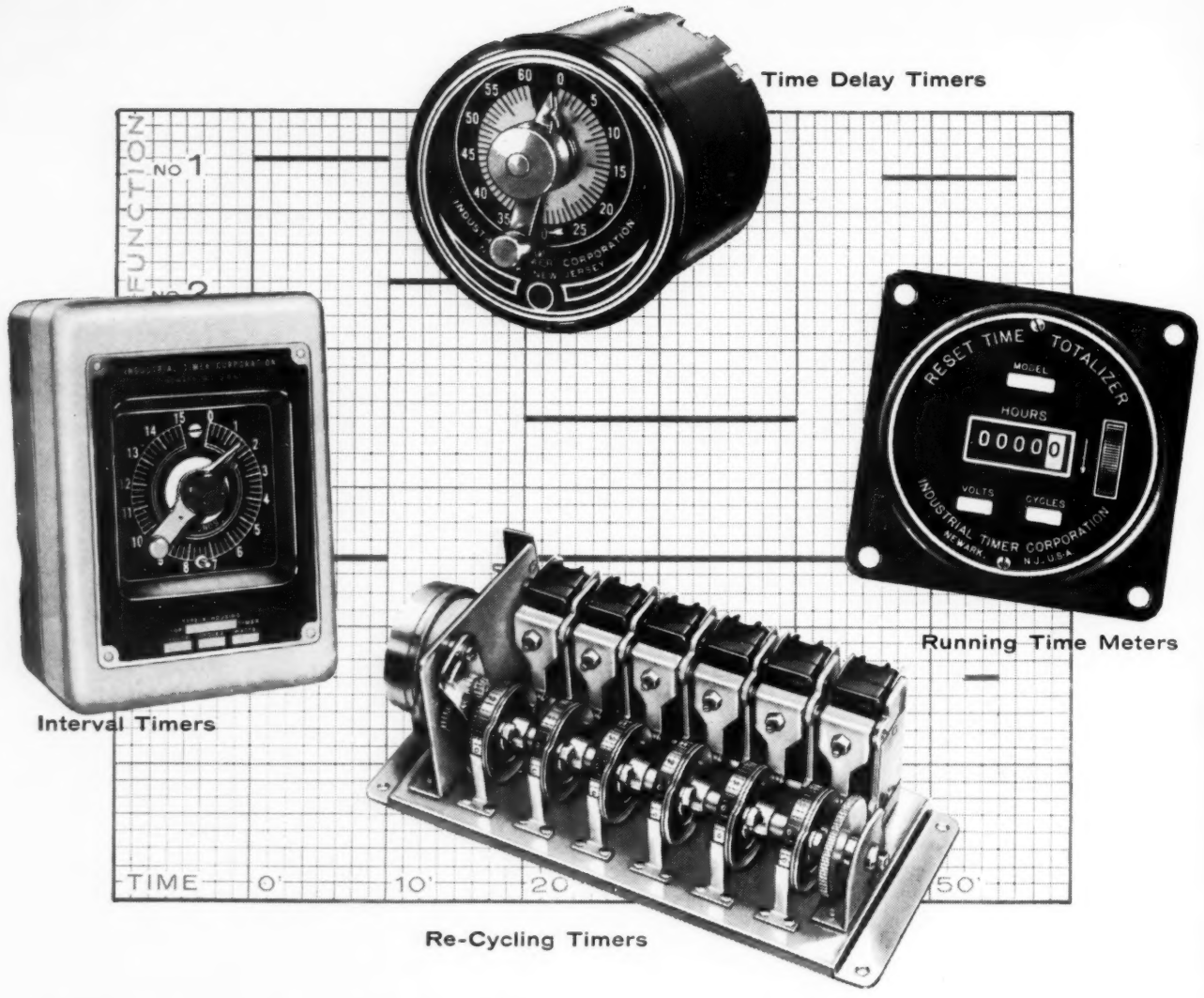
In this issue:
Components Digest 8, Part III, Microwave Switches



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The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3 NO. 11

NOVEMBER 1959

ELECTROMECHANICAL components & systems DESIGN

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Published monthly by Benwill Publishing Corporation. Harold G. Buchbinder, President; Milton Berns, George Palken, Robert B. Brotherston, Vice Presidents, Executive, Editorial and Subscription Office 1357 Washington St., West Newton 65, Mass. Telephone BIgelow 4-9006. Copyright 1959 by Benwill Publishing Corporation. Accepted as controlled circulation publication at Orange, Conn.

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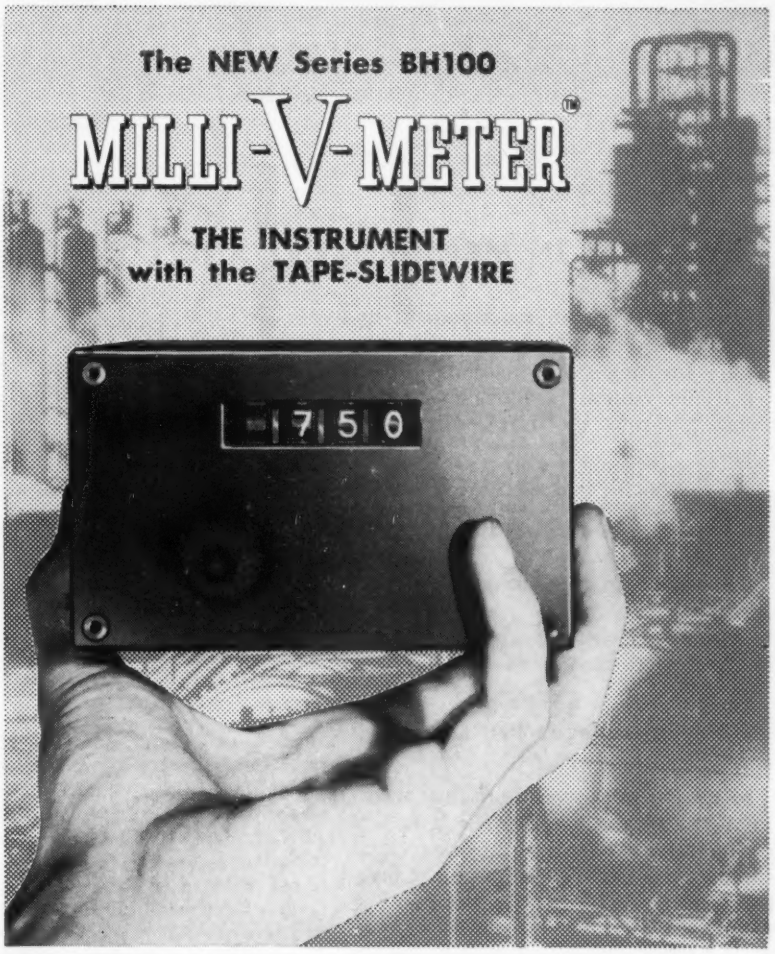

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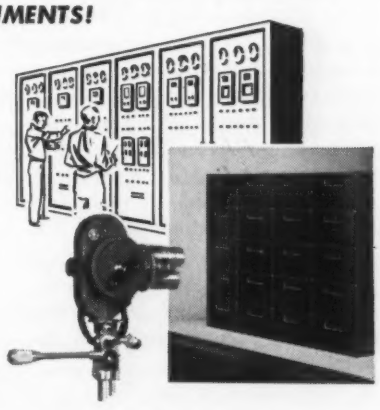

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CIRCLE 3 ON INQUIRY CARD

NEW IDEAS IN MEASUREMENT AND CONTROL

Many new ideas in measurement and control were presented at the 14th Annual Instrument-Automation Conference and Exhibit in Chicago last September. From the large number of papers worthy of review we have chosen to report on four of particular interest to electromechanical engineers:

- Flow measurement for computer control.
- A new voltage-to-digital conversion technique.
- A new torque-gage without sliprings.
- A new thermo-drive actuator.

Flow Measurement for Computer Control

The prospects of improving flow measurement with the automatic insertion of correction factors are excellent through the use of a computer. Closer and higher speed control, an increase in useful information about the system, more rapid decision making, improved product quality and lower product cost are all advantages to be gained from computerized systems. That the many advantages can actually be achieved will depend very much on the adequacy of the instrumentation.

These conclusions were developed by James H. Kogen, Chief Development Engineer, GPE, Chicago, Ill. in a paper on "Flow Measurements for Computer Control". Pointing out that addition of the computer to automatic control systems adds an entire new range of problems to the field of flow measurements, Mr. Kogen discussed some of the problems in building flow transmitting equipment that will allow maximum use of the computer. Important factors considered were:

- ease with which the transmission signal can be entered into the computer;
- noise content in the transmission signal including that caused by pulsation;
- accuracy of measurement depending on the type of computer and the application;
- range of measurement;
- dynamic response which may have to be relatively fast in order to satisfy some computer demands;
- the possibility of linear flow signals where they can be of advantage.

Discussing dynamic response of the flow transmitter, Mr. Kogen emphasized that the computer will ask the control system to perform tasks that the human operator of today does not require, and that these tasks will requrie higher response in the control loops. What the dynamic response of the flow transmitter must be is anybody's guess, he said. Rather than conjecture what might be needed Mr. Kogen preferred to speculate on what can be done with industrial components available on today's market. The theoretical closed loop response of such a system (see Fig. 1) is in the order of 15 cps, he estimated. Use of aircraft type servo valves, strain-gage and crystal pressure transducers and other high response components, he said, can undoubtedly extend the response.

Pointing out that a transmitter output that is linear with flow has many advantages both within the control loop and in conjunction with the computer, Mr. Kogen described methods whereby differential pressure signals, which are

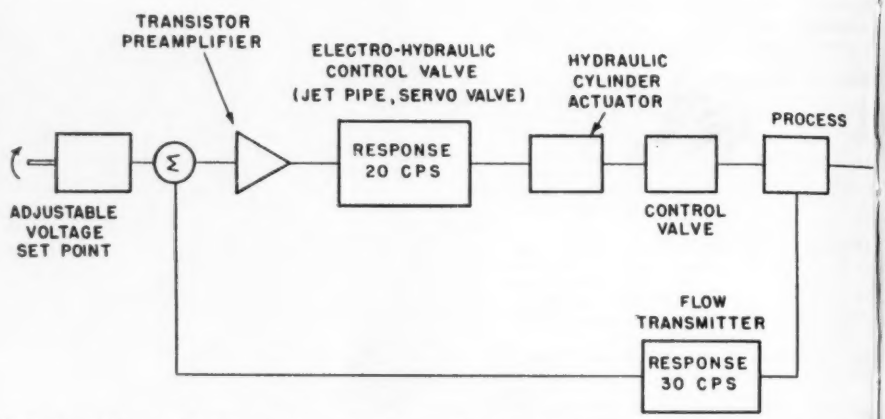

Fig. 1—Block diagram of a flow control loop illustrating what can be done to achieve high dynamic response using industrial components available on today's market. Electrical interconnection is assumed, thus, time lags and dead time due to signal transmission are effectively eliminated. The flow transmitter has a frequency response of 30 cps. The controller is a floating type, the actuator being a hydraulic cylinder. Major time constants in the system are found in the 30 cps transmitter and the hydraulic relay which exhibits a second order resonance of about 20 cps. Dead time between the orifice and valve as well as compressibility and inertial effects in the hydraulic system have been ignored, since in a practical design it would be necessary to keep these factors small. The theoretical closed loop response is in the order of 15 cps.

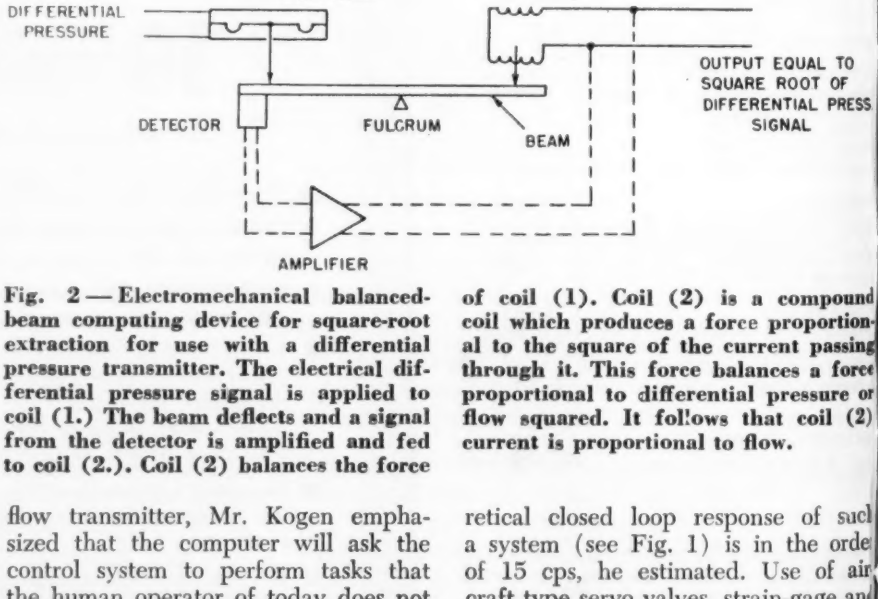

Fig. 2 — Electromechanical balanced-beam computing device for square-root extraction for use with a differential pressure transmitter. The electrical differential pressure signal is applied to coil (1.) The beam deflects and a signal from the detector is amplified and fed to coil (2.). Coil (2) balances the force of coil (1). Coil (2) is a compound coil which produces a force proportional to the square of the current passing through it. This force balances a force proportional to differential pressure or flow squared. It follows that coil (2) current is proportional to flow.

proportional to the square of flow, can be linearized.

One method of square root extraction is that of using a computing device at the output of the differential pressure transmitter. Such devices are available in electronic and electromechanical forms. The electronic device uses standard analog computing techniques. The electromechanical device shown in Fig. 2 is a balanced beam arrangement. The principle of Fig. 2 can be incorporated in flow transmitters to provide a linear-flow signal without the necessity of additional elements. Fig. 3 shows a flow transmitter of this type. Another method of square root extraction, similar in many respects to the potentiometric type recorder, is the servo balance type shown in Fig. 4. An advantage of this method is the compatability of the output with digital computer systems through use of a shaft position encoder.

Circle 87 on Inquiry Card

New Voltage-to-Digital Conversion Technique

In introducing a new analog-to-digital conversion technique for electronic data handling systems, R. A. Anderson and H. B. Schultheis, Jr. of Dymec, Inc., Palo Alto, California pointed out that during the past decade the electronic counter has evolved into an extremely versatile and dependable instrument; few instruments or measurement techniques can match the accuracy and resolution attainable with present-day electronic counters. Because of these advantages, they said, electronic counters are now finding wide use as key elements in data handling systems, where quantitative information must be sampled, measured, converted, translated, stored and recorded. Many output coupling devices are now available which permit transfer of data from electronic counters to such output machines as electric typewriters, tape perforators, card punch machines, printers and electronic computers.

Usefulness of the electronic counter in these types of data-handling systems has been increased still further through the development of the new voltage-to-frequency converter described by Andersen and Schultheis. When used with an electronic counter, the instrument comprises an analog-to-digital converter or a digital voltmeter which permits direct measurement and indication of d-c voltages on the display register of the electronic counter. The converter makes it possible to design and assemble complete data-handling systems around the versatile electronic counter.

Commonly used voltage - to - digital converters, they said, though capable of high accuracy and reliability in many applications, share the common disadvantage that variations in signal level during the instant of measurement, or superimposed noise, can introduce substantial errors. In the electro-mechanical analog - to - digital converter input noise can result in hunting and over-shooting of the output shaft carrying the code disc. In the weighing method and ramp method high amplitude impulse noise, if occurring at or near the instant of coincidence, can result in very large errors in the output information.

In addition to their noise susceptibility, these three conversion methods have a further common limitation; they are not directly capable of performing the functions of integration, averaging, and totalizing frequency required in electronic data handling systems. The new method of voltage-to-digital conversion, they said, is distinctly different from the above three. In addition to the basic function of analog-to-digital conversion, it offers the advantages that the accuracy of the output data is virtually unaffected by most types of noise on the input signal, and the important functions of integration, averaging and totalizing can be directly performed with high accuracy.

The new converter consists of a summing integrator in which the unknown voltage is applied to one input and a train of internally-generated pulses of opposite polarity is fed to the other input. One pulse is generated each time the integrator output voltage reaches a preset level. The result is that the integrator is effectively clamped, and a count of the number of pulses is proportional to the integral of the unknown voltage for the period of the count. Since the rate of generation of pulses is at any instant proportional to the input voltage, the converter and an electronic counter can be combined to serve as an averaging digital voltmeter. Sensitivity of the present converter model is 10,000 cps per volt, permitting direct digital display of four-digit d-c voltage data with a one-second gate interval on the counter.

Operation of the voltage - to - frequency converter is based on the standard analog computer integrating circuit

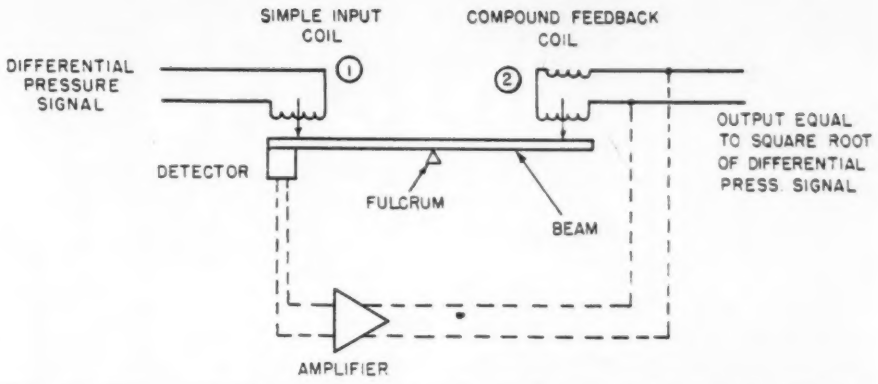

Fig. 3—Flow transmitters incorporating the principle of Fig. 2 to provide a linear flow signal without the necessity of additional elements. Coil (1) of figure 2 is replaced with a diaphragm that produces a force proportional to differential pressure. Operation is identical to that of the unit in Fig. 2

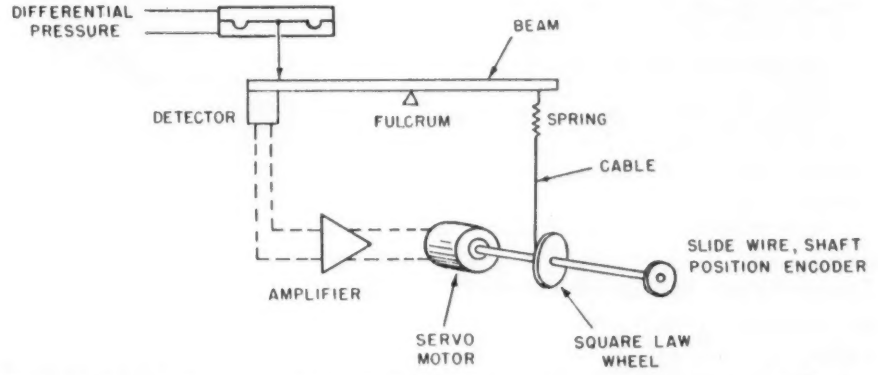

Fig. 4—Servo-balance method similar in many respects to the potentiometer type recorder. Differential pressure applied to the diaphragm, if unbalanced, causes deflection of the detector. The detector signal is amplified and the servo motor runs until the feedback spring force balances the diaphragm force. Use of cams, or linkages, provides for accurate square root extraction. Because of the high force levels available to reduce the steady state deflection of the diaphragm to zero, extremely good accuracy can be obtained.

which utilizes a chopper-stabilized operational amplifier. The basic operation of an analog integrator is illustrated in Figs. 5 and 6. In the voltage-to-frequency converter, impulses are fed back to a second input at the proper rate to establish equilibrium with the d-c signal applied to the first input. Fig. 7 shows how the equilibrium condition is maintained. The circuit shown in Fig. 7 would not respond to a positive value of e_{in}. To accommodate both polarities of input, an additional feedback loop is incorporated, as shown in Fig. 8.

Further development of the instrument is being directed toward improving its accuracy and increasing its sensitivity and resolution. Laboratory models having better than ±.05 per cent accuracy and 100 kc per volt sensitivity have been built and demonstrated.

Circle No. 80 on Inquiry Card

Torque-Gauge Without Sliprings

Orvar Dahle of the ASEA Research Laboratory in Vasteras, Sweden described a new ringshaped torque-gauge to be stationarily mounted around a shaft with an air gap of the order of a tenth of an inch. The gauge measures the change in permeability of the shaft at 45° to the axis, which change is essentially proportional to the torque and induces a proportionate output voltage that for a heavy shaft at normal mechanical loading is of the order of 10 volts across 10 kilo-ohms, sufficient for driving indicating and recording instruments without any amplification.

THE PROBLEM

In many industries, Mr. Dahl said, there is a need for a robust torque-gauge for rotating shafts that can be calibrated with reasonable precision, and if possible with a reasonably linear

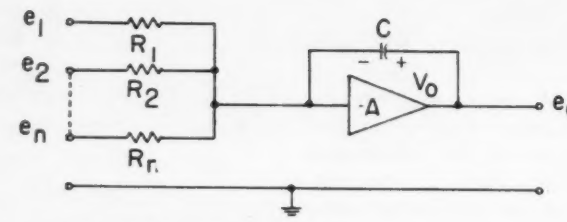

Fig. 5—Basic operation of the analog integrator. Assuming a high value of amplification (A), the operation of the integrator circuit is represented by the equation:

$$e_o = -1/R_1C \int e_1 dt - 1/R_2C \int e_2 dt \ldots$$
$$\ldots . -1/R_nC \int e_n dt + V_o$$

where V_o represents the initial charge on C at time t = o.

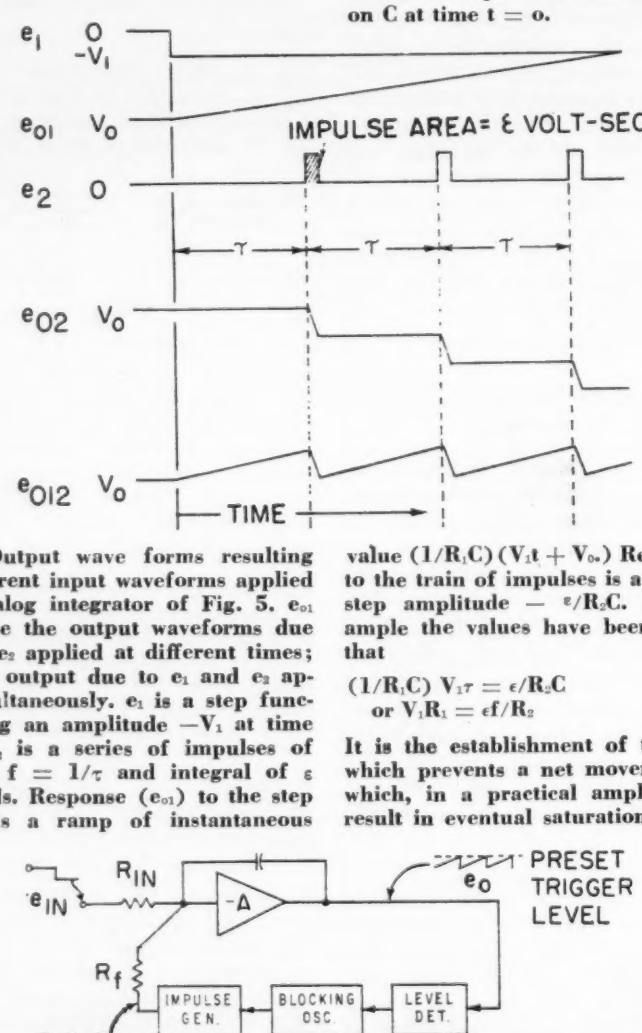

Fig. 6—Output wave forms resulting from different input waveforms applied to the analog integrator of Fig. 5. e_{o1} and e_{o2} are the output waveforms due to e_1 and e_2 applied at different times; e_{o12} is the output due to e_1 and e_2 applied simultaneously. e_1 is a step function having an amplitude $-V_1$ at time t = 0. e_2 is a series of impulses of frequency $f = 1/\tau$ and integral of ε volt-seconds. Response (e_{o1}) to the step function is a ramp of instantaneous value $(1/R_1C)(V_1t + V_o)$. Response (e_{o2}) to the train of impulses is a staircase of step amplitude $-\epsilon/R_2C$. In this example the values have been chosen so that

$$(1/R_1C)\, V_1\tau = \epsilon/R_2C$$
$$\text{or } V_1R_1 = \epsilon f/R_2$$

It is the establishment of this balance which prevents a net movement of e_{o12} which, in a practical amplifier, would result in eventual saturation.

Fig. 7—A negative d-c voltage applied to the input terminal causes the output e_o to rise linearly with time. As e_o rises above a preset trigger level in the Level Detector, a single impulse is generated. This impulse immediately resets e_o to some value below the trigger level. From there e_o begins to rise again and eventually triggers off another impulse. The process continues to repeat itself and the equation

$$(e_{in}/R_{in}) = (\epsilon f/R_f)$$

is assured.

If R_{in} = 1M, R_f = 500K, and ε = 50 microvolt-seconds, then

$$f = (R_f e_{in}/R_{in}\epsilon) = [(500 \times 10^3 \times e_{in})/(10^6 \times 50 \times 10^{-6})] = 10^4 \times e_{in} \text{ cycles per second}$$

That is, the sensitivity of the voltage-to-frequency converter in this case may be expressed as 10 kc/volt.

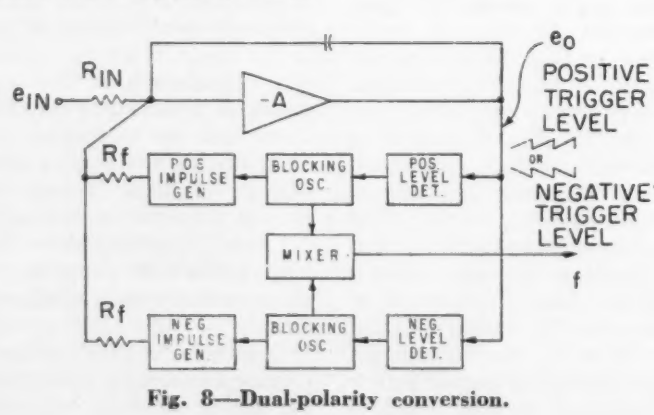

Fig. 8—Dual-polarity conversion.

characteristic. In many cases robustness and insensitivity to dirt and moisture are of utmost importance, and from this point of view sliprings are most undesirable. A high output power and a not too high output impedance are on the other hand very essential in order to make the gauge insensitive not only to dirt and moisture but also to stray fields from neighboring power cables.

In most industrial installations no reduction of the existing shaft diameter is permissible, and in many cases it is impossible to insert a special calibrated measuring shaft, but the torque measurement has to be performed on the existing shaft to which the least possible modification should be made. In many cases, only a rather short free length of a few inches is available.

For precision measurement, variations in voltage, frequency and temperature should not impair the accuracy, and the hysteresis should be negligible. Negligible hysteresis is also very essential for control purposes since appreciable hysteresis could result in serious hunting. The torque-meter should also be independent of rotational speed of the shaft preferably down to zero rpm so that calibration can be performed statically.

The ringtorductor designed to satisfy these requirements is best described as a redesign and improvement on a crosstorductor introduced six years ago. Both units, classed as torductors are based on the principle that the permeability of a steel shaft increases in one 45 degree direction from the shaft axis and decreases at another 45 degree direction in proportion to torque applied to the shaft. Method of operation of the crosstorductor is illustrated and described in Figs. 9 and 10.

The crosstorductor output voltage as a function of torque is shown in Fig. 11 for different values of magnetizing ampere-turns, where increasing index corresponds to increasing ampere-turns. Low magnetization results in low sensitivity and, what is worse, a very marked hysteresis.

The hysteresis decreases with increasing magnetization and at the same time both sensitivity and linearity are improved up to a certain value for the magnetization. With even higher magnetization, lower sensitivity is obtained and the linearity between the torque and the output voltage is impaired.

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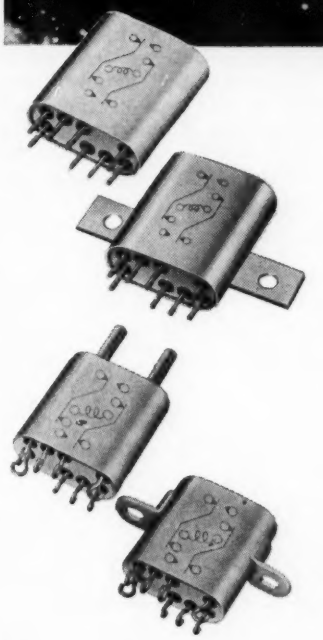

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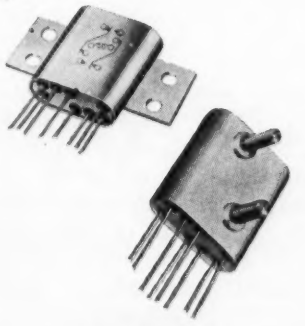

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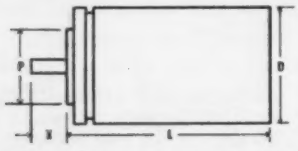
A full line of step-servo motors, sizes 5, 8, 11, 15 and 23, designed for digital-to-analog conversion in 45° increments up to 120 pulses per second, are manufactured by Induction Motors of California. The motors are available with impedance of 15 to 300 OHMS and voltage range of 20 to 50 VDC. Motors operate over a range of −55°C to +125°C and meet environmental requirements of MIL-E-5272B and MIL-E-5400. Stainless steel construction is used, and no mechanical detents are employed.

GENERAL SPECIFICATIONS FOR STEP-SERVO MOTORS



I. M. C. P/N	Dim. in Inches D	L	P	X	Rotor Inertia GM-CM²	Min. Holding Torq. Oz.-In.	Max. Watts Per Ø
005-801	.500	1.20	.375	13/32	0.50	0.5	8
9708-024	.750	1.09	.500	11/32	0.65	0.8	10
011-859	1.062	1.36	.625	3/8	0.65	1.4	15
9711-007	1.062	1.76	.625	3/8	2.5	1.4	15
9711-050	1.062	1.78	.625	3/8	2.5	1.2	15
9711-053	1.062	1.36	.625	3/8	2.5	1.0	15
9715-001	1.437	1.75	.875	3/8	2.5	1.8	25
023-801	2.250	1.75	2.00	5/8	5.0	3.0	50

Information on cost, delivery, or additional technical information, as well as information on synchro components and solenoids, is available when requested on your company letterhead.

Induction Motors of California

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CIRCLE 5 ON INQUIRY CARD

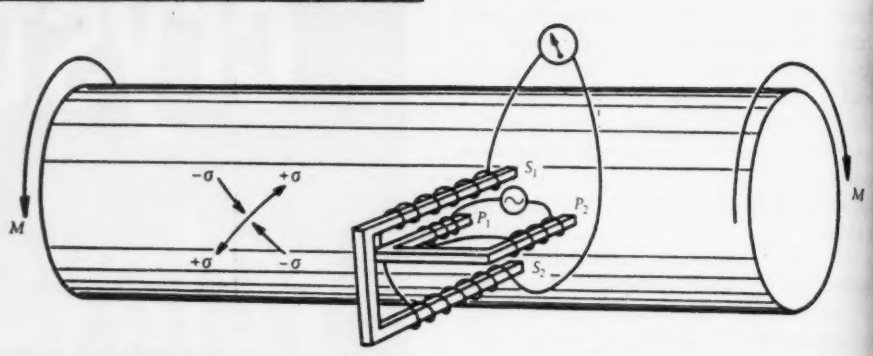
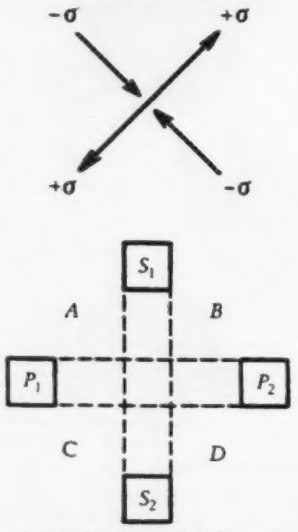
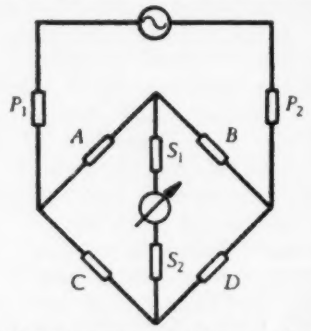


Fig. 9 Principle of the crosstorductor. The design consists of two U-shaped laminated iron-cores, equipped wth windings and mounted at right-ang'es to each other in a measuring head which is placed adjacent to the shaft with one core parallel to the axis of the shaft and with an airgap of about a tenth of an inch between the shaft and the poles of the two iron-cores. One core is magnetized with a-c, normally 50 or 60 cps, and in principle induces a symmetrical magnetic field in the shaft surface. Because of the symmetry, no flux passes through the other core at zero stress. However, the magnetic potential pattern is distorted by torque, which results in a proportionate flux in the secondary core. The output is of the order of 1 volt over 50 kilo-ohm.



(a) Reluctance bridge of crosstorductor



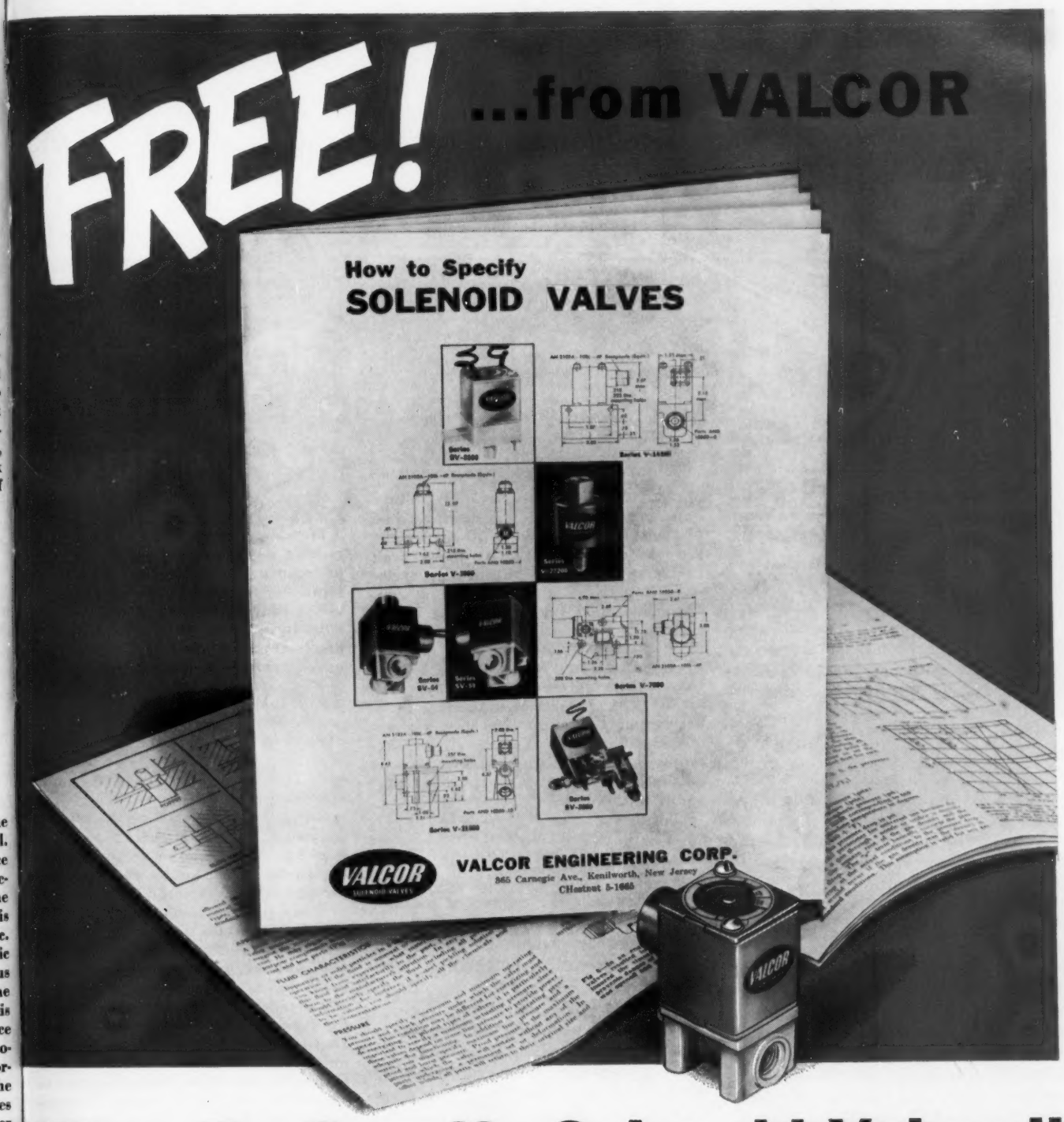
(b) Wheatstone bridge analogy

Fig. 10 Method of operation of the crosstorductor shown in more detail. Fig. 10a represents the shaft surface immediately in front of the crosstorductor. *A* represents the reluctance in the shaft surface between P_1 and S_1, *B* is the reluctance between S_1 and P_2 etc. The four reluctances form a magnetic bridge which is completely analogous to an ordinary Wheatstone bridge. The corresponding electrical analogy is shown in Fig. 10b, where the a-c source corresponds to the exciting electromagnet P_1-P_2 and the galvanometer corresponds to secondary core S_1-S_2. The resistances P_1, P_2, S_1 and S_2 in series with the source and the galvanometer represent the corresponding airgap reluctances. It is assumed that the shaft material is intrinsically isotropic. The reluctances *A*, *B*, *C* and *D* are then all of equal magnitude for an unloaded shaft and the magnetic bridge is thus completely balanced. When the shaft is subjected to torque, which results in the principal stresses ±σ as shown in the figure, the reluctances *A* and *D*, which lie in the direction of tension will be reduced whereas the reluctances *B* and *C*, which lie in the direction of compression, will be increased. The result is that an unbalanced magnetic flux will flow through the bridge arm S_1-S_2 in proportion to the reluctance changes which, under suitable conditions, are proportional to the impressed torque.

netic anistropy is, however, not only caused by stress of external or internal origin but also by a possible orientation of the crystals.

Due to the fact that the crosstorductor measures the stress only in the surface under the measuring head, any lack of uniformity in the stress pattern around the circumference of the shaft will cause a corresponding change in the torductor output voltage when the shaft is rotated. An example of how the output voltage (rms-value) can vary around the circumference is shown in Fig. 12.

When the shaft rotates, these stress variations will cause a corresponding modulation of the output voltage. This modulation must obviously be filtered out from the rectified output before the output can be used for regulation purposes. For this filtering a time



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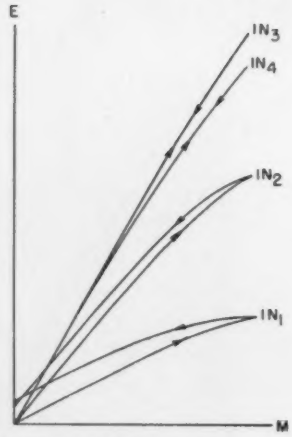


Fig. 11 Crosstorductor output voltage vs. torque for different values of magnetizing ampere-turns.

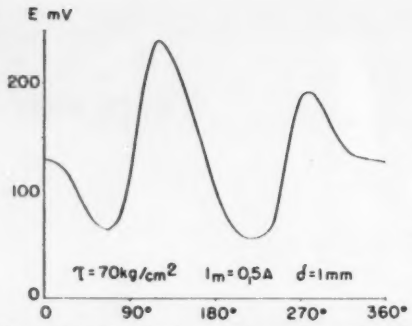


Fig. 12 Variation of crosstorductor output voltage around circumference of test shaft.

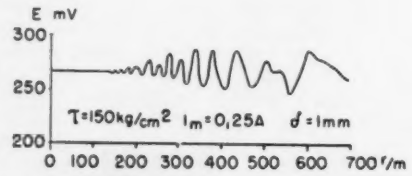


Fig. 13 Crosstorductor output voltage vs speed shown for constant torque. The curve is measured at 50 cps for the test shaft of Fig. 12. At these peak values vs speed, the output also varies slowly up and down with time at constant rotational speed. This can be explained by a phase shift of the magnetic pattern relative to the internal stress pattern of Fig. 12. When a peak value of the internal stress pattern coincides with a point of maximum magnetization, the output reaches a maximum vs time, and when the stress maximum coincides with a point of zero magnetization, the output has a minimum vs time.

constant of the same order as the time for one revolution must be used. This confines the use of the crosstorductor to regulation problems that are slow compared to the rotational frequency of the shaft since the necessary filter otherwise would introduce a disturbing time-lag in the control loop.

Speed dependence is also a limitation due to rotation; eddy currents cause a transverse field in the surface of the shaft underneath the two energized pole-surfaces in much the same way as the armature reaction is produced in electrical machines. If the torductor is asymmetric this will cause a secondary voltage component that is proportional to the speed but independent of the torque. If the measuring poles are symmetrically arranged this effect is, however, eliminated.

A more serious speed dependence is caused by residual magnetization of the shaft by the torductor. The effect is most easily explained by comparison with a magnetic recorder, the shaft being the recording medium, the torductor primary core the recording head and the secondary core the play-back head. When the shaft is stationary, the remanence does not play any significant role. When, on the other hand, the shaft rotates, a magnetic pattern is recorded in the shaft surface by the torductor primary core. With no torque, the field from this magnetic pattern has no effect on the torductor secondary since it is balanced for this field in the same way as it is for the torductor primary field. With torque, however, the residual field is distorted in the same way as the primary field, and when this distorted field passes the torductor secondary core an additional voltage is induced, which in principle is proportional to the torque, the degree of residual magnetization and the speed. The degree of residual magnetization is on the other hand in itself speed dependent. At low speed the field patterns for neighboring half-cycles overlap, so that the "recording" is continuously erased, eliminating the speed dependence. When the speed is higher and of such a value that the exciting frequency is an exact multiple of the rotational frequency, the magnetic pattern, recorded under one revolution, exactly coincides with the next one. This gives a "recorder voltage" in phase with the stationary torductor voltage, resulting in output voltage maxima at these synchronous speed values. Fig. 13 illustrates the speed dependence of the crosstorductor.

THE RINGTORDUCTOR

The shortcomings of the crosstorductor have been eliminated to a very high degree in the ringtorductor. In the new design, the torductor has become a ring surrounding the shaft and somewhat resembling the stator of an electrical machine, the shaft being the rotor. The principle of operation is illustrated in Fig. 14.

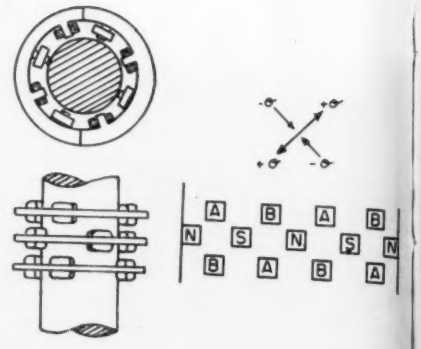
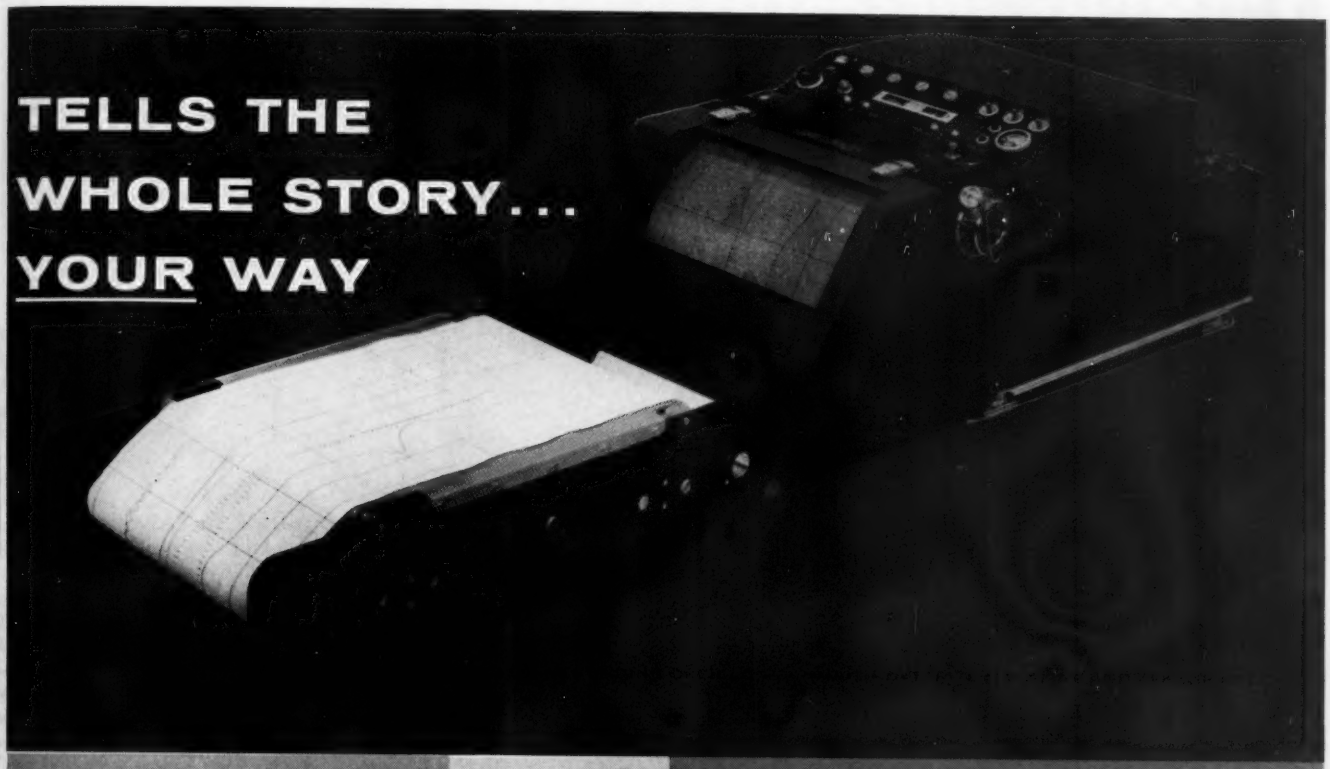


Fig. 14. The ringtorductor consists of 3 identical pole-rings with a number of poles always chosen as a multiple of 4 to reduce the influence of the ring joints necessary for easy mounting of the torductor around the shaft. The poles are fitted with coils with alternately reversed winding directions. The middle ring is displaced half the pole-pitch relative to the outer rings and the distance between the rings is approximately equivalent to half the pole-pitch. The middle ring is normally used as primary and excited with 50 or 60 cps. The two outer rings are used as secondaries and connected in series, with mutually reversed winding directions, as indicated by the letters *A* and *B* in Fig. 14c, which shows the evolution of the shaft surface under the ringtorductor and the projection of the poles. The primary poles are marked *N* and *S* depicting a certain instant in the magnetizing cycle. If the shaft is unloaded and without internal stresses the magnetic fields between the different *N*- and *S*-poles will be symmetrical so that the zero equipotential lines will be situated symmetrically under the secondary poles *A* and *B*. The secondary flux and hence the secondary voltage is thus zero at zero stress. When torque is applied to the shaft the principal stresses ± σ indicated in Fig. 14c are obtained. The permeability in the direction of tension, between the poles *B* and *S* and between *A* and *N* is then increased, while the permeability in the direction of compression, between the poles *B* and *N* and between *A* and *S* is decreased. Thus all *A*-poles come magnetically nearer to the *N*-poles and all the *B*-poles magnetically nearer to the *S*-poles. The result is magnetically the same as if the secondary rings had been tangentially displaced in mutually opposite directions and opposite to the torsion of the shaft. The resulting fluxes through the poles cooperate in inducing an output voltage in the series-coupled windings. The output is normally of the order of 10 volts and 1 milliamp; large enough for an instrument without any amplification.

CEC's 5-119 Oscillograph with 3 interchangeable magazines



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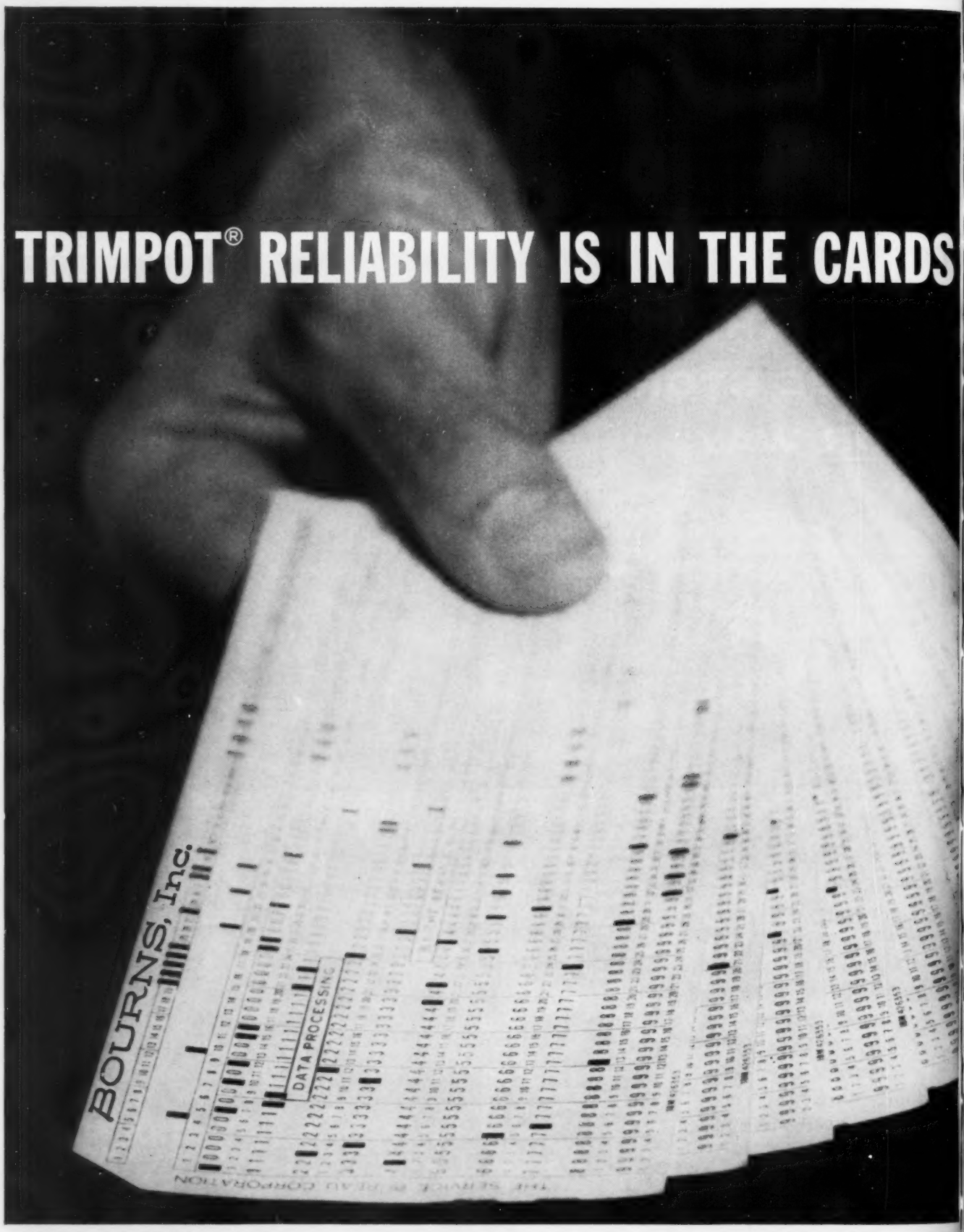

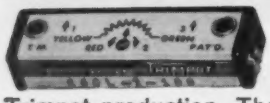

Test information punched in these cards can provide detailed performance reliability statistics on Trimpot production. The cards summarize extensive environmental tests which Bourns regularly conducts above and beyond regular quality control. In Bourns' own Reliability Assurance Laboratory, monthly samples are taken at random from factory stocks and completely tested for conformance to all environmental and electrical specifications on Trimpot catalog sheets. Results can then be fed into IBM computers which analyze performance data with corrective action taken immediately, if required!

This program is the only one of its kind in the industry. Only Trimpot potentiometers are tested so thoroughly, so frequently. In short, Trimpot reliability is a fact—one you can put in your next circuit.

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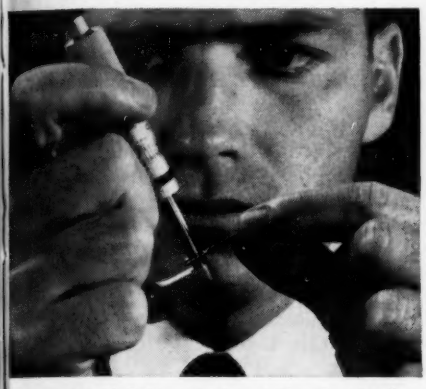
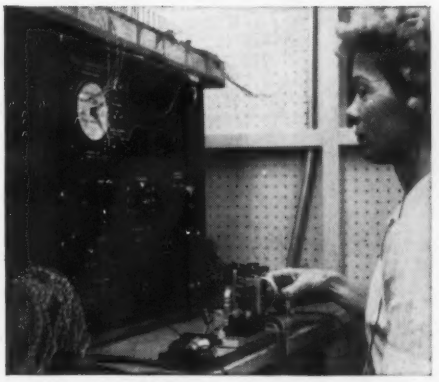


Trimpot reliability starts at the beginning. Here an incoming lot of potentiometer leadscrews undergoes a dimensional check.

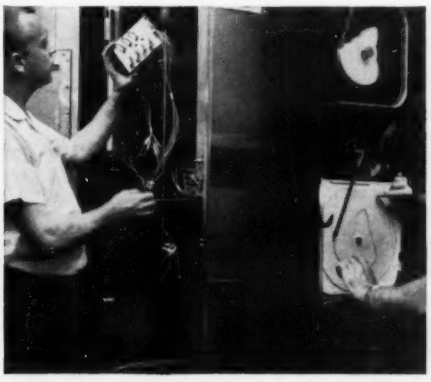
From the time the element is wound until the lid of the potentiometer is installed, in-process inspection monitors quality.



100% final inspection is made possible by this exclusive high-speed system developed by Bourns to test all major electrical characteristics. Critical dimensions of each unit are also checked.

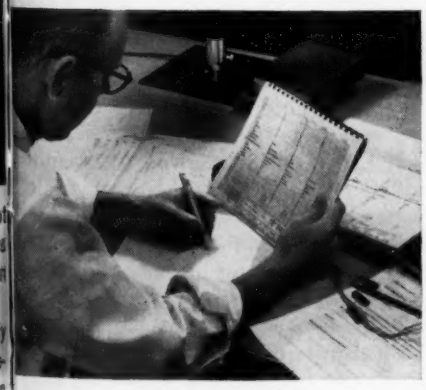
And Reliability Assurance Tests Like These...

This vibrator for measuring conformance to Mil-Specs is an important part of the extensive equipment in Bourns Reliability Assurance Laboratory.



This chamber subjects potentiometers to standard military tests for humidity, provides important feedback on product performance.

1000-hour load life testing per Mil-R-19A takes place in ovens like this, which hold temperatures at desired levels at full rated power.



When tests are completed and the results tabulated, Bourns engineers plot frequency distribution curves from the steady flow of test results. Analysis of these curves and other data from testing provides a continuing check on all models to see that they meet the most exacting standards of performance. This analysis and the constant flow of information between the Testing and Production departments is your assurance that the Trimpot potentiometers you specify and purchase will meet specifications.

Write for the new 8-page folder describing the Bourns Reliability Assurance Program and a copy of the Trimpot Summary Brochure.

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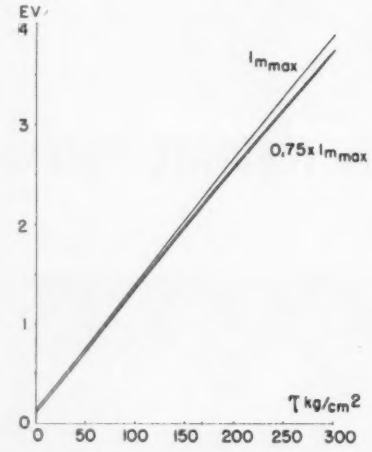

Fig. 15 The output voltage of the ringtorductor vs. stress shown for the test shaft of Fig. 12. The magnetizing current $I_{m\ max}$ giving maximum output voltage gives also obviously the best linearity and the best freedom from hysteresis. At a magnetizing current of 75% of $I_{m\ max}$ the linearity is, however, nearly as good and the hysteresis also very small. Even if this value does not here show any advantages over $I_{m\ max}$, Fig. 16 shows that it can be desirable from the point of view of speed-dependence.

Since the measurement with the ringtorductor is made nearly continuously around the shaft, the 45°-stresses are virtually integrated around the circumference and the modulation of the output voltage is thus reduced to a very small value.

For the test shaft, for which the modulation of Fig. 12 was measured with the crosstorductor, the modulation with the ringtorductor is only $\pm 0.5\%$ at 240 kg/cm² (3400 psi) and the modulation frequency is 8 times the rotational frequency (8 poles) and thus much less detrimental from a regulation point of view. Because of this the ringtorductor can be used for fast regulation problems which lie outside the scope of the crosstorductor. Figs. 15 and 16 show the performance of the ringtorductor.

The effective response time of the ringtorductor is mainly determined by the exciting frequency and the desired degree of filtering of the output signal. For 50 to 60 cps excitation it can be of the order of 10 to 30 ms, dependent on the circuitry chosen.

Since both the zero and the sensitivity now are a result of an integration around the circumference, the ringtorductor can be statically calibrated with good accuracy.

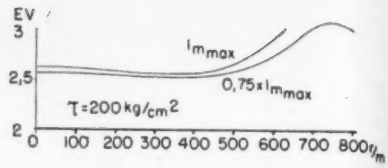

Fig. 16 Output voltage of ringtorductor vs rotational speed for the test shaft of Fig. 12 at a stress of 200 kg/cm² (2840 psi) and a magnetizing frequency of 50 cps. For $I_{m\ max}$ the speed dependence is not negligible even at low speeds. At 75% of $I_{m\ max}$ the speed dependence is obviously much less marked and up to 500 rpm (200 mm shaft, 8-poles) the variation of the output voltage with speed is very small. For both values of magnetizing current there is a maximum at 750 rpm, the synchronous speed (8 poles). At this speed the residual magnetic pattern recorded under one halfcycle exactly coincides with that for the following halfcycle. As in the crosstorductor case, this pattern induces a "recorder voltage" in the secondary which is in phase with the stationary torductor voltage at the synchronous speed, resulting in a marked maximum in the output voltage. Since the speed dependence is a result of the residual magnetization, it is quite natural that it increases with increasing excitation.

If the speed for a certain application is so high that the speed dependence becomes disturbing, this can always be cured by choosing a higher excitation frequency which increases the speed-independent speed range proportionately. This applies naturally both to the crosstorductor and the ringtorductor.

New Thermo-Drive Actuator

The Swartwout Company of Cleveland, Ohio has applied the concept of boiling a liquid to provide large accurately controlled working forces in an entirely new type of valve actuator. Mr. Earl O. Sweitzer, Swartwout Chief Mechanical Engineer who designed the unit, discussed the problems in applying this concept and predicted the resulting thermo-drive actuator will materially increase applications of electronic control to industrial processes.

Figure 17 shows the important components that make up the actuator. In operation of the actuator, heat is continuously poured into the cylinder by means of an electrical resistance strip heater. This constant addition of heat causes the liquid to boil and to create vapor at a constant rate.

If the vapor is allowed to accumulate, it will drive the diaphragm-sealed piston to a fully stroked position and pressure will continue to rise. The diaphragm is the means of converting the produced pressure to a force and resultant movement.

Electrical control is brought into the device by means of a moving force coil energized by the controller output

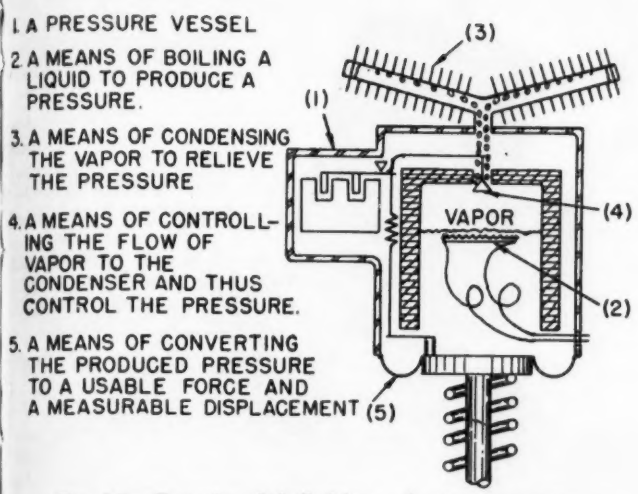
1. A PRESSURE VESSEL
2. A MEANS OF BOILING A LIQUID TO PRODUCE A PRESSURE.
3. A MEANS OF CONDENSING THE VAPOR TO RELIEVE THE PRESSURE
4. A MEANS OF CONTROLLING THE FLOW OF VAPOR TO THE CONDENSER AND THUS CONTROL THE PRESSURE.
5. A MEANS OF CONVERTING THE PRODUCED PRESSURE TO A USABLE FORCE AND A MEASURABLE DISPLACEMENT
(1)
(2)
(3)
(4)
(5)
VAPOR

Fig. 17—Functional definitions of actuator parts.

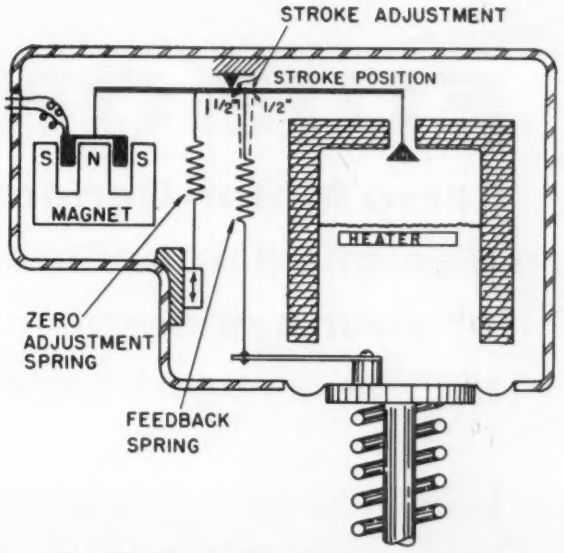

Fig. 18—Feedback mechanism of actuator.

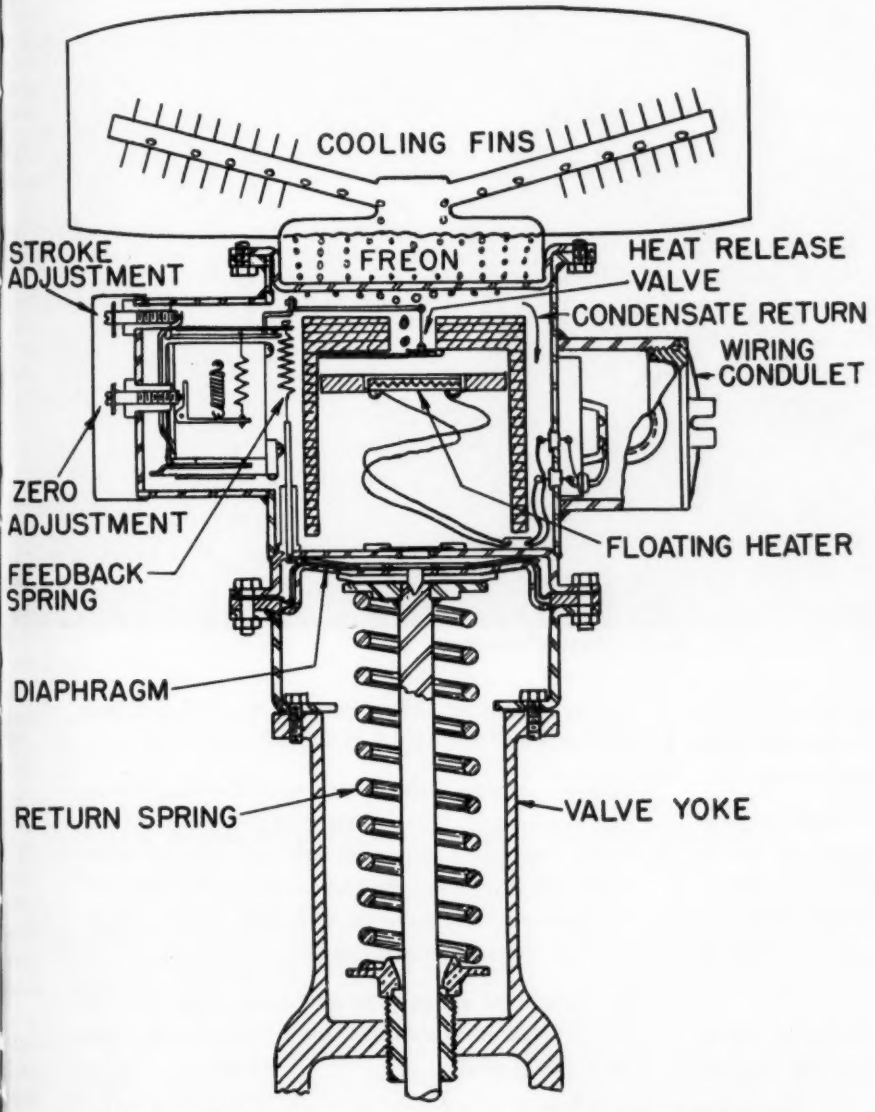

Fig. 19—Cross-section diagram of thermo-drive actuator.

signal. This small signal is easily able to move the heat release valve and thus control the escape of heat to the condenser.

In steady state operation heat in is equal to heat out. To change the position of the piston it is only necessary to change the rate of heat escape to the condenser. If the heat release valve is closed, pressure builds up and the piston moves downward pulling on the end of the feedback spring. When this spring has stretched sufficiently to balance the force from the force coil the heat release valve reopens sufficiently to allow the constant input of heat to escape in the form of vapor bubbles to the cool condenser surface where it passes to the air by means of cooling fins. Fig. 18 is a schematic diagram showing the operation of the feedback mechanism.

Mr. Schweitzer pointed out that in many respects the device is analogous to a vacuum tube amplifier. The small amount of energy needed to actuate the heat release valve is of similar magnitude to the small amount of energy required to drive the grid. The heater in the Thermo-Drive produces a flow of vapor instead of a flow of electrons as in a vacuum tube.

The constant flow of heat into the device and the controlled flow of heat out through the heat release valve provide a system that is very sensitive and capable of very good response. Speed of the actuator is 1/10 inch per second. Fig. 19 is a cross section diagram of the complete actuator unit.

Earlier models of the Thermo-Drive required use of expensive custom-built bellows capable of high pressure, long stroke operation. Pressure operating ranges of these models were in the order of 200 to 400 psi. Use of a friction-free rubber and fabric bellows-diaphragm, called a Bellofram, in the present model allows reduction of operating pressure to less than 40 psi. This inexpensive rolling diaphragm furnishes a leakproof seal and, Schweitzer said, assures the dependability and simplicity required of a process valve actuator. (See the lead article, on Belloframs; in the October Issue of ELECTROMECHANICAL DESIGN).

For more information on the Thermo-Drive actuator . . . circle 89 on inquiry card.

THOMAS A.

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VIDEO RECORDER CAPTURES RADAR TRACKING SIGNALS

Recording Head Assembly Revolving At 14,400 RPM Packs Video Signals on Magnetic Tape Moving at 15 IPS

The frequency range of radar signals is still too high to be recorded directly by any known means. To record radar signals, engineers convert them to lower frequencies. But the extent of conversion that can be accomplished accurately is limited, leaving the high frequency radar signals out of range of most recorders. Using a helical method of recording, which permits video information to be packed on magnetic tape in tight vertical tracks, Ampex Corp. of Redwood City, Cal. has developed a system they call the Videotape Recorder that accurately records radar signals picked up in tracking missiles. Video response of the recorder is uniform within 3 db from 15 kilocycles to 2.5 megacycles. The system has been used very successfully by missile test centers on hundreds of "hot" missile firings.

The important factor the recorder adds to missile data evaluation is that, through its use, various portions of the missile's trajectory may be restudied without need to screen thousands of feet of film from optical systems. And the time delay encountered in developing the film is eliminated because the recorder can play back the recordings immediately.

RECORDING HEAD DESIGN

Although basic recording principles would lend themselves admirably to Videotape recording, the video signal presents a space challenge. Containing frequency components in a range that approaches dc at the low end and extends to over 4 megacycles at the upper end, it requires more tape area than does the audio spectrum. For example, a conventional audio recorder, operating at a tape speed of 7½ inches per second, records a 15-kilocycle signal at a rate of 2 kilocycles per inch of tape,

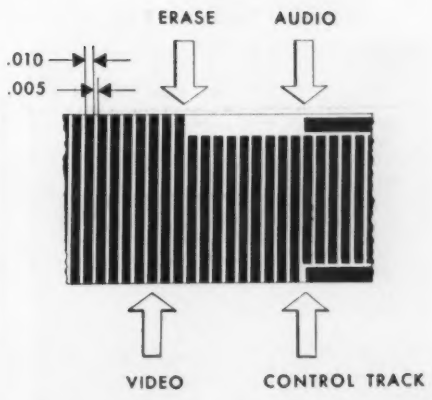


Fig. 1—Diagram showing how the different tracks of information are recorded on video tape. Videotape recording of radar signals is done in successive narrow, vertical bands on the tape by four tiny video heads which have a minimum life of 100 hours of recording time with normal routine maintenance. Sound or audio recording can be captured longitudinally along one edge of the tape. Simultaneously with the video and audio recording, a control track is recorded longitudinally along the opposite edge of the tape. This control track provides for perfect synchronization of tape and recording heads.

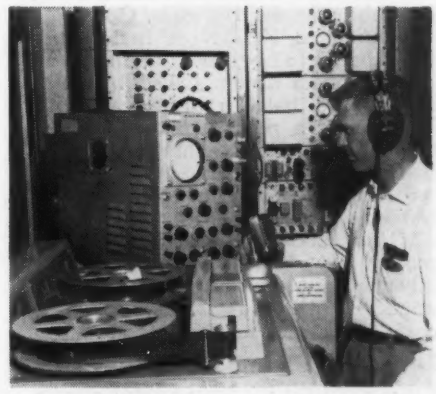


Fig. 2—Robert J. Clawson of the White Sands Missile Range's Signal Missile Support Agency, New Mexico, operates an Ampex Videotape TV recorder as it captures radar signals picked up from the flight path of a "hot" missile firing. The complete recording and reproduction system, which consists of electronics and a tape transport, fits into one double electronics rack and one console requiring less than 100 square feet of floor space. With 12½ inch reels, the machine provides up to 64 minutes of recording time. Tape motion and modes of operation are controlled at the right-hand control panel on the console, or at a remote control unit. Correct operation of the system may be readily checked with indicators located on the control panel.

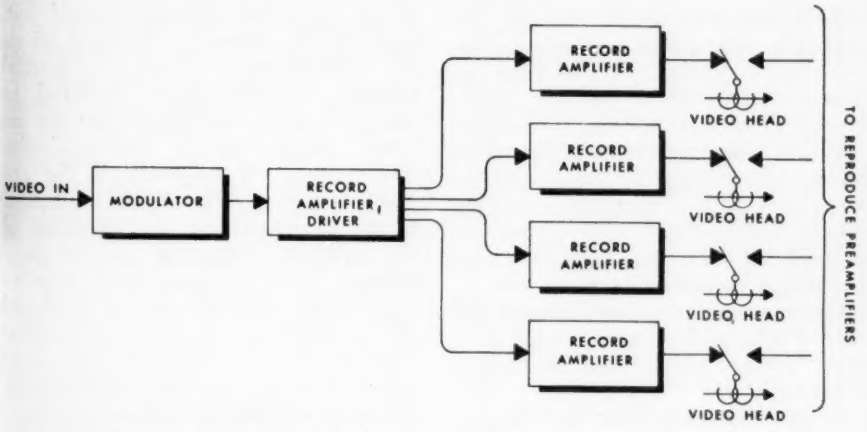


Fig. 3—Simplified block diagram of the recording function.

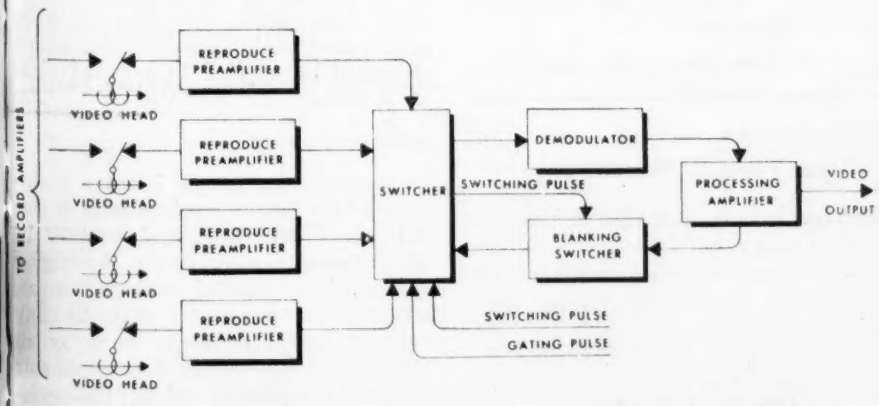
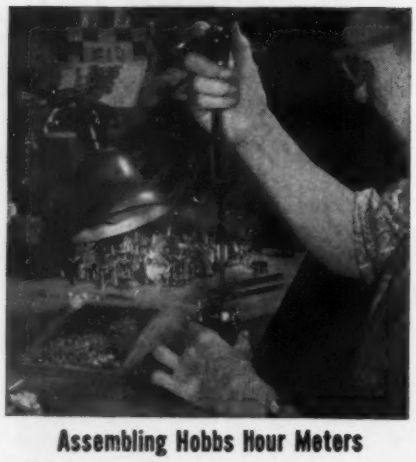


Fig. 4.—Simplified block diagram of the reproducing function.

Locking screws with LOCTITE increases production 23%



Assembling Hobbs Hour Meters

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"We all try to cut costs. For example, we used a resin-type product to hold screws in assembling Hobbs Hour Meters. It was necessary for a girl to dip a little piece of wire into the compound, transfer it to the screw hole, and then assemble the screw. With 18 screws this was a slow and tedious job. We switched to LOCTITE Sealant and increased production while making the job easier for the girls. Operators now produce 23% more meters per hour thanks to LOCTITE! This increased production is accomplished by tumbling large batches of screws with LOCTITE in a polyethylene bag. The screws, treated and ready, are spread in front of the operator within easy reach. LOCTITE will not harden in air, but sets firmly when screws are assembled. LOCTITE saves us time and money by virtually eliminating the labor of applying the staking compound to the screws. LOCTITE cut costs for us with no effort at all."

LOCTITE is a thin liquid that hardens when confined between closely fitting metal parts. One drop replaces all size lock nuts, lock washers, lock screws, staking, jam nuts and interference threads. It forms a tough heat and oil resistant bond that resists any amount of vibration . . . yet ordinary tools will remove fasteners. LOCTITE requires no heating or mixing . . . treated parts can be stored for days . . . lock only when assembled. Write for literature and free sample.

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thus the wave-length of that signal as it appears on the tape is ½ millimeter. To record a 4-megacycle signal so that its wave-length on the tape would be ½ millimeter (assuming the use of the same type head) would require a tape speed of 2,000 ips—well over 110 mph.

Obviously, to provide an hour of Videotape recording with this method would require a reel of gigantic proportions. A study revealed that the use of very precise heads—incapable of being produced in quantity—could result in the required tape speed being reduced to approximately 200 inches per second, but a reel-to-reel tape speed of this magnitude still proved too high for a practical machine, since it resulted in a playing time (using reels of tape of a reasonable size) far too short to allow necessary recording time for test operations. It is interesting to note that a reel 38 inches in diameter, containing 60,000 feet of tape, would be required to provide a playing time of 1 hr. at a speed of 200 in./sec.

To solve the problem, Ampex developed a special, revolving head assembly capable of helical recording. The 2-inch wide magnetic tape, moving at only 15 inches per second, curves past a rotating disc with 4 equally spaced magnetic heads. Despite the seemingly slow speed of the tape, information is packed rapidly onto the magnetic tape. Each head—in turn—records successive narrow, vertical bands of video information. Speed of the head assembly is 14,400 revolutions per minute. In this way, a head-to-tape velocity approaching 1500 inches per second is attained. Simultaneously with the helical recording of the video information, stationary heads record the audio tracks and a control track in a linear manner along opposite edges of the tape.

Ampex engineers say that despite the electronic complexity of this uniquely designed head assembly, no specialized employees are required to operate the recorder.

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WORTH FILING

Voltage Tunable Magnetrons

26 page bulletin provides information on four new S-band packaged voltage-tunable magnetrons. Information includes data on designs, typical applications, operation and manufacturing. Theoretical data also is presented

Source: General Electric Co.
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INERTIAL GUIDANCE WITHOUT GIMBALS

Inertial Components On An Unstabilized Base

When inertial components are used on an unstabilized base the rotation of the base may generate extraneous torques which do not exist when the component is used on a stabilized base. If these torques occur about the sensitive axis of an inertial component operating on the principle of a torque balance, then the indicated output of that component will have an error proportional to the magnitude of the extraneous torque. Last May at an ARS Controllable Satellites Conference held at M.I.T. Henry F. Blazek, Project Supervisor of Ford Instrument Company's Missile Development Division, discussed the nature of the extraneous torques, the order of magnitude of the errors in specific existing designs, and the methods by which the error may be minimized.

Until recently, virtually all precision inertial systems employed gimbaling to isolate inertial components from the motion of the vehicle. The geometric reference frame maintained by the inertial components has either been fixed in space or else has rotated only fast enough to keep it earth-referenced. Now, Mr. Blazek pointed out, considerable attention is being given to applications in which the inertial components are rigidly mounted to the body of the vehicle. Since the inertial components in such a body-fixed system are subjected to the angular motion of the vehicle, it is necessary to investigate the meaning of the indicated output of inertial components when the component is on an unstabilized base. Mr. Blazek analyzed the problem as it applies to inertial devices having a sensitive axis about which a torque balance is maintained. He assumed that the servo maintaining the torque balance operates with negligible error. Since this category includes most of the conventional inertial components, including all gyroscopic devices, the results of his analysis could be applied to a broad class of important components.

ERROR SOURCES

In general, the torque balance maintained by a servo involves both a signal torque and a control torque. In nongyroscopic components the signal is usually an inertial reaction torque, whereas the constraint may be any readily controlled torque such as an electromagnetic torque. In components utilizing a spinning wheel the gyroscopic torque may either be a signal

as in a rate gyro or a constraint as in an integrating gyro accelerometer.

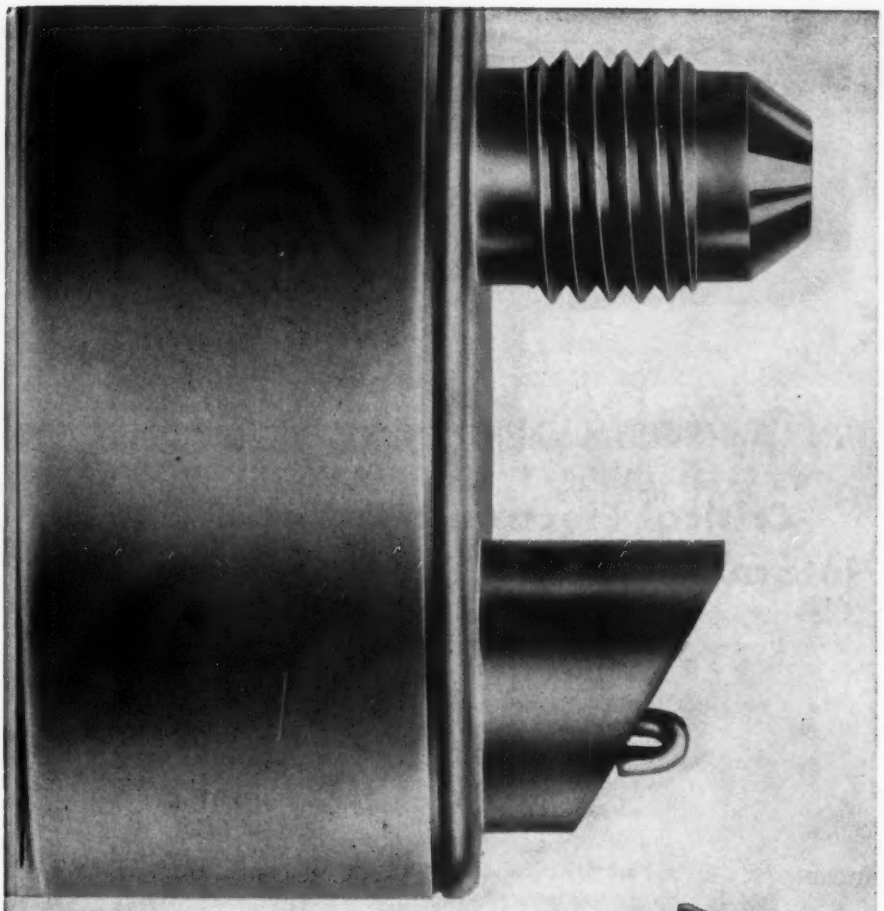
Precision of the component depends upon a known relationship between the signal torque and the constraining torque. If a rotation of the base introduces extraneous torques about the component's sensitive axis, an error will be introduced into the indicated out-put unless a correction is made. Two such extraneous torques are the centrifugal torques arising from an angular velocity about an axis normal to the sensitive axis, and the inertial reaction torque arising from an acceleration about the sensitive axis.

To obtain a feeling for the order of magnitude of errors that result from the uncompensated use of existing components on an unstabilized base, Mr. Blazek studied two important examples: the rate gyro and the integrating gyro accelerometer. His mathematical analysis showed that an in-put rate of one radian per second normal to the measuring axis of a typical rate gyro he studied resulted in an error in indicated rate of 0.01% due to centrifugal torque while the input rate about the sensitive axis resulted in an error in indicated angular position of 1 milli radian due to inertial reaction torque.

His analysis of the error introduced into the indicated output of an integrating gyro accelerometer when it is used on an unstabilized base closely paralled the treatment of the rate gyro. However, Mr. Blazek's analysis considers only the errors caused by the generation of extraneous torques. He assumed that engineers are aware of the fact that the indicated output of an accelerometer changes as a result of motion of the base about the accelerometer measuring axis. Errors of this type may be eliminated by applying a correction based on attitude information. Again his mathematics showed that the effect of input rates of 1 radian per second normal to the measuring axis of the typical integrating gyro accelerometer was as follows. The input rate about the gyro spin axis resulted in an error in indicated acceleration of 0.0273% due to centrifugal torque while the input rate about the gyro sensitive axis resulted in indicated velocity of 0.3 meters per second due to inertial reaction torque.

MINIMIZATION OF ERRORS

Since centrifugal torque is directly proportional to a difference in two moments of inertia, Mr. Blazek suggested that the centrifugal torque be made negligibly small in any specific component by designing these two moments of inertia to be equal. His second possible solution would be to compute a correction for centrifugal torque based



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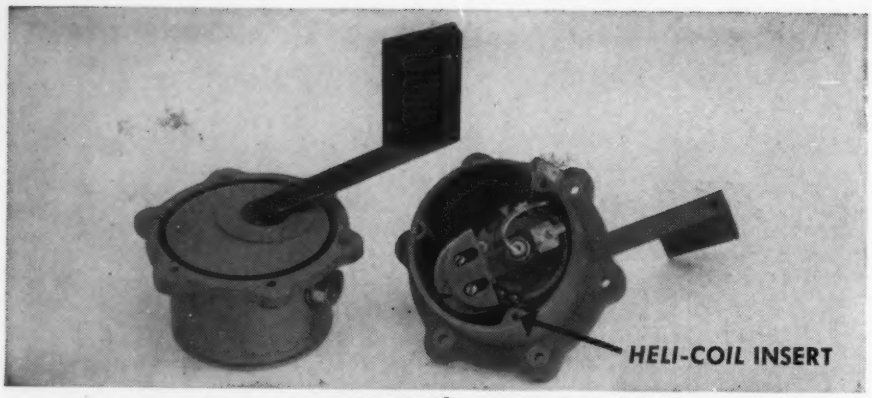

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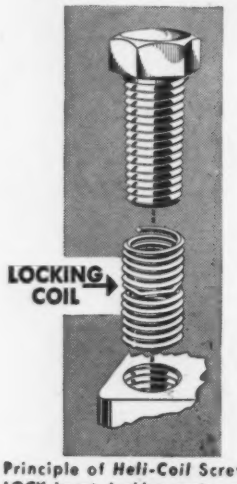

Principle of *Heli-Coil* Screw-LOCK Insert. Locking center coil grips internally, holds screw firmly.

Electronic control devices for aircraft and missiles, like this angle of attack vane transducer made by U. S. SCIENCE CORPORATION, LOS ANGELES, CALIF., have to withstand severe vibration, impact, corrosion and temperature change. They must be made of light materials and still have strong threads — able to hold fasteners tightly and stand frequent assembly and disassembly.

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- permit repeated disassembly and reassembly
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upon attitude rate information derived from one of the other components Since the error is small the correction need not be very accurate.

The extraneous inertial reaction torque presents a somewhat different problem. Whereas the centrifugal torque may be minimized in the design of the component without affecting the level of the signal torque, the inertia about the sensitive axis is inherent to the component and cannot be modified without a corresponding modification of the signal torque. Mr. Blazek concluded, therefore, that if a system analysis were to show the inertial reaction torque to be a problem then the error would have to be minimized by computation. He noted that the inertial reaction torque tends to integrate to zero in a vehicle traveling with a roughly constant attitude, whereas the centrifugal torque, being proportional to the product of two angular velocities, may not integrate to zero.

Telemetry Receiver

Telemetry receiver, designed for airborne applications where performance is of greater importance than size and weight, features phase-lock detection. This double super-heterodyne receiver obtains a noise figure of less than 8 db by use of a grounded grid RF amplifier followed by a 6AK5 triode connected mixer. To achieve the desired stability of ±.002 percent of the received frequency, the first local oscillator is quartz crystal controlled and is front panelled for quick changeability. The final amplifier is ganged to the RF circuits enabling the receiver to be put in operation on any frequency by plugging in the desired crystal and setting a single tuning dial to the appropriate frequency. The second oscillator incorporates a vernier capacitor, tunable from the front panel to provide calibrated frequency deviations of ±150kc. The receiver also offers a choice of two IF amplifiers of different bandwidths which can be made from the front panel by means of a selector switch. Included in each receiver is a peak frequency deviation meter with full-scale ranges of 25, 75, and 150 kilocycles and is useful in setting up the desired frequency deviation of individual sub-carriers using FM/FM or peak deviation of pulses used in PWM/FM. Nems-Clarke Co., Silver Spring, Maryland.

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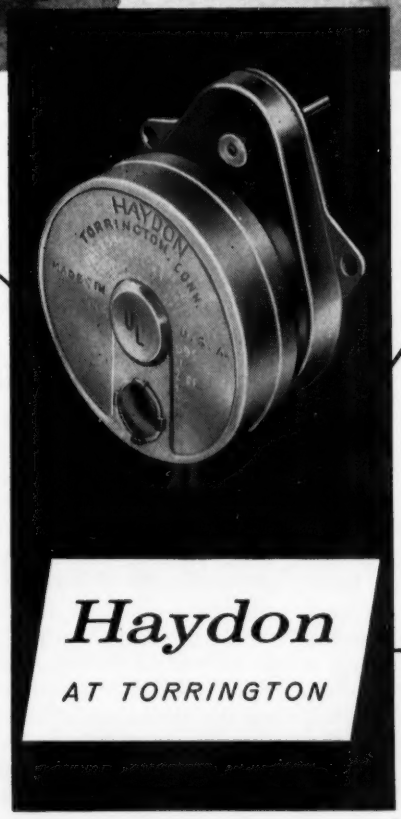

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MATERIALS

FERRITES FOR ELECTROMECHANICAL APPLICATIONS

Materials engineers are beginning to build materials to order, to design materials with properties prescribed for the purposes at hand. By observing and understanding the underlying molecular phenomena in materials, engineers are no longer shackled by available materials and their empirical performance characteristics but can dream up completely new devices. Ferrites are examples of such materials being tailored to various needs. This article based on information supplied by Kearfott Company, Inc., Little Falls, N. J. describes characteristics of ferrites developed for gyros, microwave devices, and electromechanical transducers.

Development since World War II of a new class of ferromagnetic materials called ferrites has been instrumental in the design of many new devices. Ferrite materials occupy a unique place in electromechanics. They combine moderate magnetic permeability with high volume resistivity. Although some alloys have permeabilities several orders of magnitude higher than ferrite, they require laminations because of eddy-current losses when they are employed in an alternating field. Ferrites can be produced without costly laminations and can be formed in any convenient shape by ceramic techniques. They are available commercially for applications in devices such as flyback transformers, antenna rods, recording heads, computer cores, tuning cores, gyros, synchronous motors, microwave devices, traveling wave tubes, electromechanical filters and power transducers. This article discusses characteristics of ferrites developed for some of the newer applications. Ferrites can be grouped into three classes: spinel crystalline structures; hexagonal or magnetoplumbite crystalline structures; and garnet crystalline structures. The spinel type are an outgrowth of magnetite FeO, Fe_2O_3. By substituting various oxides for iron oxide, the materials engineer has been able to develop a wide variety of materials having properties tailored to the needs of almost any application.

Magnetoplumbite ferrites are similar to the natural mineral magnetite, or lodestone. The formula for them may be expressed as xMO . YFe_2O_3, where M is usually barium, lead, or strontium. These materials are used almost exclusively as permanent magnets and have been designed into periodically focussed traveling wave tubes.

Garnets, the newest type of ferrite, can be expressed by the formula $3M_2O_3$. $5Fe_2O_3$ where M_2O_3 can be almost any of the rare earth oxides. These materials have found application in several types of microwave devices.

FERRITES FOR MOTORS

Recently ferrites have been used as stators and rotors in floated gyros. Their chemical inertness and lower specific gravity, when compared to those of laminated stacks normally employed, favor a broadening use of ferrites in such applications. These characteristics are particularly important in components that operate at higher ac frequencies, for as the frequency of operation increases, eddy current losses observed in laminated stacks become excessive. To overcome this loss, thinner laminations must be used. However, as the trend continues toward component size reduction, it is not always possible to make thinner laminations and still achieve good mechanical design and stability. Moreover, in floated gyroscopes the laminated stack has been known to deteriorate in the suspending medium.

Ferrites, because of their mechanical inertness and because no organic material is required to laminate them, have electrical and mechanical properties that remain unchanged with time. In addition, since the specific gravity of ferrites is only 60% that of the laminate, lower specific gravity suspending mediums with correspondingly lower viscosities can be used. Therefore, problems of cleaning and removing air bubbles are greatly eased.

High speed motors become more practical when proper ferrites are used for rotors since tangential and centrifugal forces exerted in ferrites as a result of rotation are considerably lower than those encountered with laminates. This is attributable to the difference between the specific gravities of ferrites and laminates. Ferrites

Fig. 1—AC flux density vs. a-c Permeability.

specifically designed for such uses have initial permeabilities of 3000 and 2100, respectively, while the maximum permeability of these materials exceeds 6000. Devices using these ferrites can be designed to provide for excitation and pickoff by following a design procedure employed with laminated stacks. The material should be operated at the peak of the ac permeability vs. ac flux density curve as illustrated in Fig. 1. Such devices normally operate with lower voltages across the exciting coils than equivalent devices with laminated stacks do.

The art of forming and manufacturing ferrites has advanced to the point where complex shapes in almost any convenient form can be made. These can be ground with diamond wheels to tolerances undreamed of a few years ago. As a consequence, exceptionally good reproductibility can be realized in physical size, structure, tolerances, and magnetic properties.

FERRITES FOR MICROWAVE APPLICATION

Ferrites were originally found by Hogan (Hogan, C. L. *The Microwave Gyrator*, Bell System Tech. J. 311-31 Jan. 1952) to exhibit a Faraday effect. This means that a radio frequency wave passing through a ferrite magnetized in the direction of propagation will have its axis of polarization rotated through an angle that increases in proportion to the distance traveled. The direction of rotation depends only on the direction of the applied magnetic field. This rotation is thus nonreciprocal since the angle of rotation would be doubled by a wave reflected

back along its path. This phenomenon has made ferrites suitable for several types of devices in microwave applications such as gyrators, circulators, isolators, and phase shifters.

Ferrites also exhibit, at microwave frequencies, a power loss or absorption which is a function of the applied magnetic field. This loss rises to maximum at some value of magnetic field which depends on the microwave frequency, specimen shape, and the composition of the material in question. The field at which maximum absorption or loss occurs is called the resonance field, and is given by Kittel's equation

$$H_{res} = \omega/\gamma + 4\pi\ (N_Z - N_X)\ M_s$$

where: H_{res} = resonance field
$\omega = 2\pi$ times the RF
γ = the gyromagnetic ratio
N_Z and N_X = demagnetizing factors
M_s = saturation magnetization

A typical ferromagnetic resonance curve is shown in Fig. 2.

Ferromagnetic resonance line width is defined as the difference between two magnetic fields at half the power absorption.

In practical devices one must keep losses as small as possible while maintaining the desired rotation or attenuation. The losses one encounters in ferrite may be classified as three distinct types.

1–Dielectric Loss: Since all materials have a finite resistivity, they all exhibit some dielectric loss. This loss is usually quite small in ferrite materials, especially in those designed for microwave use. Microwave materials normally do not have a d-c resistivity of less than 10^3 ohm.cm. This resistivity may be increased by the manufacturer through adjustment of stoichiometry, by additions, or in the sintering operation, without deleterious effects on microwave properties.

2–Low Field Loss: That portion of the ferromagnetic resonance curve marked "low field loss" is of great importance. This loss is maximum at zero applied field and decreases as the field increases. As shown by Polden and Smith (See *Resonance Phenomena in Ferrites;* Rev. Mod. Phys. 25, 89-90 1953) this loss is related to saturation magnetization and exist only if the material is not completely magnetized. For spherical shapes this loss essentially disappears at a magnetic field value of $4\pi M_s/3$. The loss observed in nickel ferrite at 10 kmc will be minimized at a value of 1000 oersteds. Magnesium ferrite has no appreciable low field loss at 10 kmc, a feature attributable to its lower value of saturation magnetization.

3–Ferromagetnic Resonance: This loss is of great importance in the design of practical devices. If the ferromagnetic

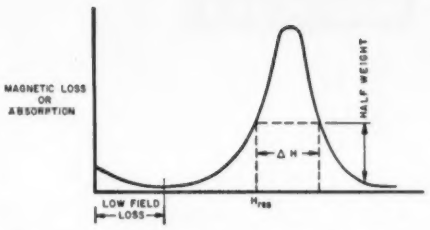

Fig. 2—Applied magnetic field h(oersteds).

resonance is broad and sweeping it is very difficult, if not impossible, to design a device that operated in the minimum loss region below resonance. In the design of resonance isolators, line width is an important criterion in determining the lowest possible frequencies of operation, together with the front-to-back ratios obtainable.

Width of ferromagnetic resonances is generally attributed to two factors. A) Line width broadening above values obtained for single crystals is primarily due to magnetocrystalline anisotrophy. In single crystals there are crystallographic directions of easy magnetization. The ferromagnetic resonance field, H (resonance), depends upon the orientation of these axes with respect to the field direction. To describe this phenomenon a magnetocrystalline anistrophy energy density is introduced. This is in the form of a constant, K, called the anisotrophy constant, which is a function of the angles between the direction of magnetization and the crystallographic axes.

The range of field values obtained for all possible orientations is on the order of K divided by the saturation magnetization. Therefore, in polycrystalline materials the line width of the ferromagnetic resonance curve may be approximated by the sum of the curves of all the randomly oriented crystallites. It is to be expected that as K is decreased, the line width will decrease as shown by Blum and Zneimer (see Physical and Electrical Properties of a Nickel Ferrite as Affected by Compositional Changes, j. Amer. Ar. Soc. 40 (6) 208-211, 1957). B) Further line broadening may be caused by the shape of the specimen used and its physical structure. This is the result of surface and internal demagnetizing factors and correspondingly demagnetizing fields, causing a difference in the internal field and the externally applied field necessary for resonance.

MAGNETOSTRICTIVE FERRITES FOR TRANSDUCERS

It has been known for a long time that nickel and nickel-containing alloys display a fairly large fractional change in physical dimensions when magnetized. It is not so well known that certain nickel, nickel-copper, and nickel-cobalt ferrites exhibit similar though less pronounced changes in dimensions when magnetized. Thus, the value for the longitudinal magnetostriction of nickel $\Delta\ 1/1$ is $-33\text{x}10^{-6}$ and for nickel ferrite, $-27\text{x}10^{-6}$.

When ferrites are magnetized, the changes in length ε, and the induction B is related to the change in field strength as shown in Fig. 3.

As a consequence of the quadratic nature of magnetostriction, a suitably shaped unpolarized core designed to resonate at a frequency f_r, may be set into resonant vibration by simply passing an alternating current of frequency $\frac{1}{2}\ f_r$ through a winding around the core. Such a core will have a response curve analogous to the one shown in Fig. 4.

The electro-acoustic efficiency of such transducers is rather poor because of hysteresis losses, but in certain applications they may be used in low power pulse operations for depth sounding. In operations of this type the transducer is left in the remanent state after each transmitting pulse and may then operate as a polarized receiver or hydrophone. Unpolarized cores cannot operate as hydrophones since the macroscopic change of induction with change of incident stress is essentially zero in the virgin state.

The hysteresis losses in high-power navigational transmitters and in industrial radiators can be reduced to a large extent when the changes in the magnetic parameters, field strength and induction, and in the mechanical parameters, stress and strain, are made small compared with the initial values. These reductions are realized through the application of a suitable magnetic bias, H_0, B_0. As a result a mechanical bias $(\Delta 1/1)_o = \varepsilon_o$ is effected. The application of these restrictions not only reduces hysteresis losses to a marked extent but increases the electro-acoustical efficiency considerably. Moreover, the quadratic magnetostrictive effect becomes effectively linear allowing the use of simple sets of linear equations of state between the four harmonic variables, H, B, ε and υ to describe the transducer system.

The magnetostrictive strain resulting from sinusoidal excitation of a biased transducer is shown in Fig. 5.

An understanding of the action of a magnetostrictive transducer can be obtained by referring to the teachings of Pierce, (See Pierce, G. E., *Proc. Amer. Acad. Arts and Science,* 63, 1, 1928) and of Butterworth, and Smith, (See Butterworth, S. and Smith F. D., *Proc. Phys. Soc.* (London) B, 43, 166, 1931) who showed such transducers behave near the mechanical resonant point like two impedances,

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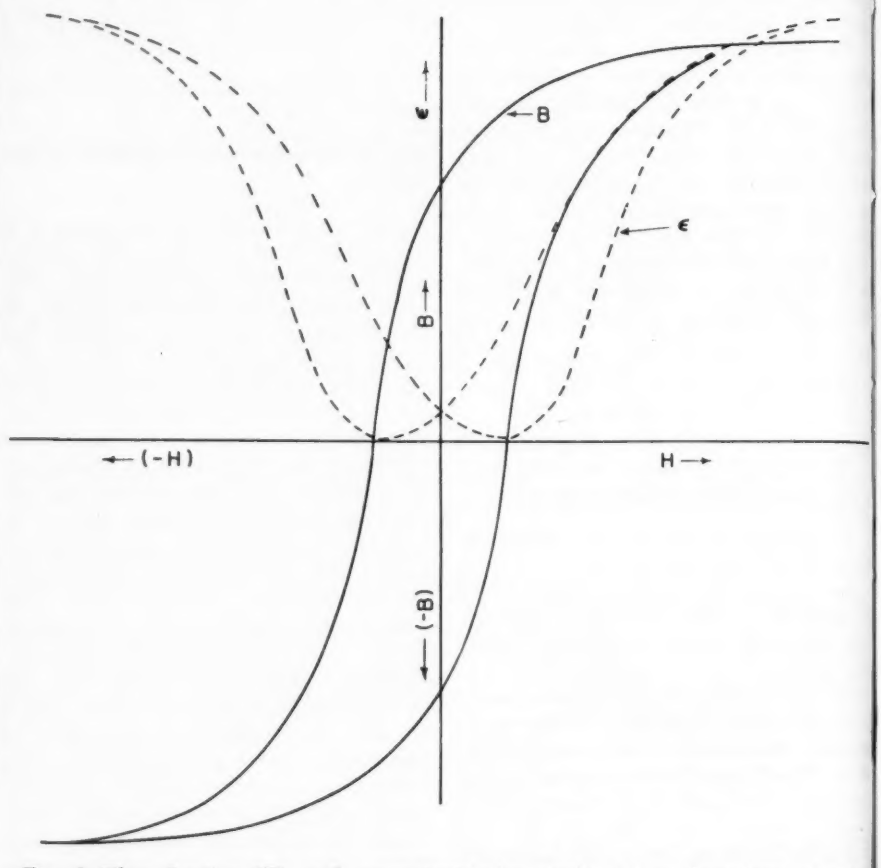


Fig. 3—Flux density (B) and magnetostrictive strain (ε) as functions of exciting field (H).

$\vec{Z}_c$ and $\vec{Z}_m$, in series.

That is, $\vec{Z}_e = \vec{Z}_c + \vec{Z}_m$.

Here, $\vec{Z}_c$ is the electrical impedance and is equal to $R_c + j\omega L_c$.

$\vec{Z}_m$ is the mechanical impedance and $\vec{Z}_e$ is the equivalent impedance of the circuit which for convenience is reproduced in Fig. 6.

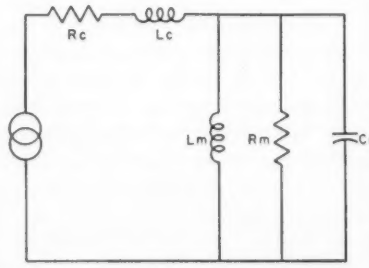


Fig. 6—Equivalent circuit electromechanical transducer.

In Figure 6 the mechanical admittance $Y_m = 1/\vec{Z}_m$ is given by the equation

$$\vec{Y}_m = 1/\vec{Z}_m = (1/R_m) + (1/j\omega L_m) + j\omega C_m \qquad (1)$$

which contains the parallel circuit elements R_m, C_m, and L_m.

Consider the case where the elements R_e and R_m are removed from the circuit. This condition may be approximated by operating the transducer completely unloaded. Under these conditions the electrical impedance $j\omega L_c$ and the mechanical impedance,

$$j\omega(L_m/1 - \omega^2 L_m C_m)$$

will be in series and the impedance of this circuit will be given by the relation

$$\vec{Z}_e = j\omega L_c + j\omega(L_m/1 - \omega^2 L_m C_m) \text{ or } (2)$$

$$\vec{Z}_e = -j\omega(\omega^2 L_m L_c C_m - L_m - L_c)/(1 - \omega^2 L_m C_m) \qquad (3)$$

In this equation there are two extreme impedance values possible:

1. If the denominator vanishes, the equivalent impedance $\vec{Z}_e$ reaches infinity at a frequency given by

$$\omega_o = (L_m C_m)^{-1/2} \qquad (4)$$

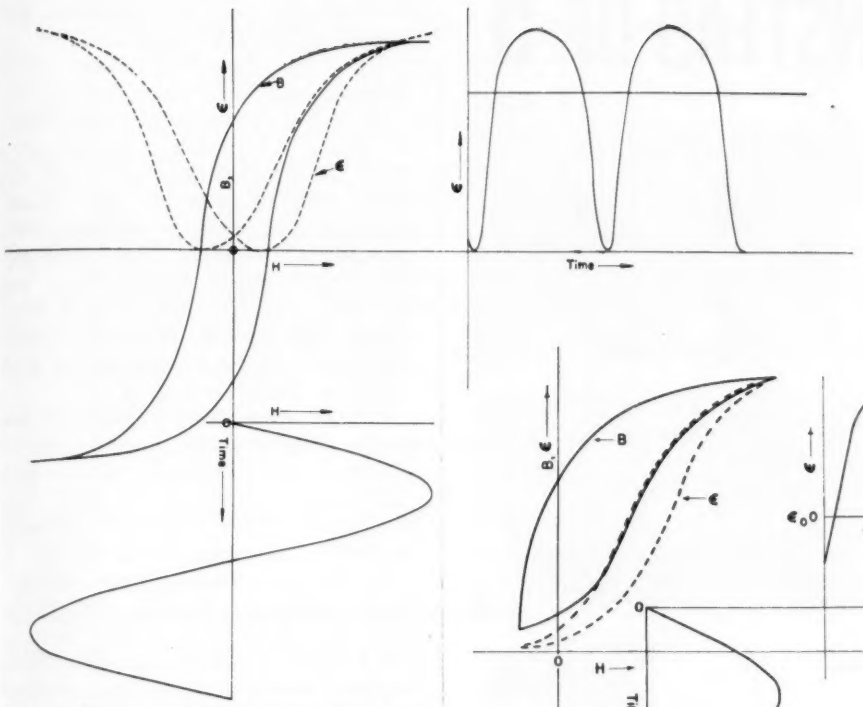


Fig. 4—Magnetostrictive strain resulting from sinusoidal excitation at zero bias.

This corresponds to the resonance frequency of the mechanical branch of the vibrator.

2. If the numerator of Equation (3) vanishes, $\vec{Z} = 0$ at the frequency

$$\omega_a = [L_m + L_c)/L_m L_c C_m]^{-½} \quad (5)$$

ω_a represents the parallel antiresonance frequency of the complete network.

Now, if the value of ω_o from equation (4) is substituted into equation (5) it is found that

$$\omega_a = \omega_o [(L_m/L_c) + 1]^{½} \quad (6)$$

If k^2, the electromechanical coupling coefficient, is defined as L_m/L_c, it is apparent that this value is the ratio of converted stored energy to input stored energy. The electromechanical coupling coefficient, k, is also related to the magnetostrictive constant λ, permeability μ, and the Young's Modulus E of the resonator as shown by the formula $k = (4\pi\lambda^2\mu/E)^{½}$

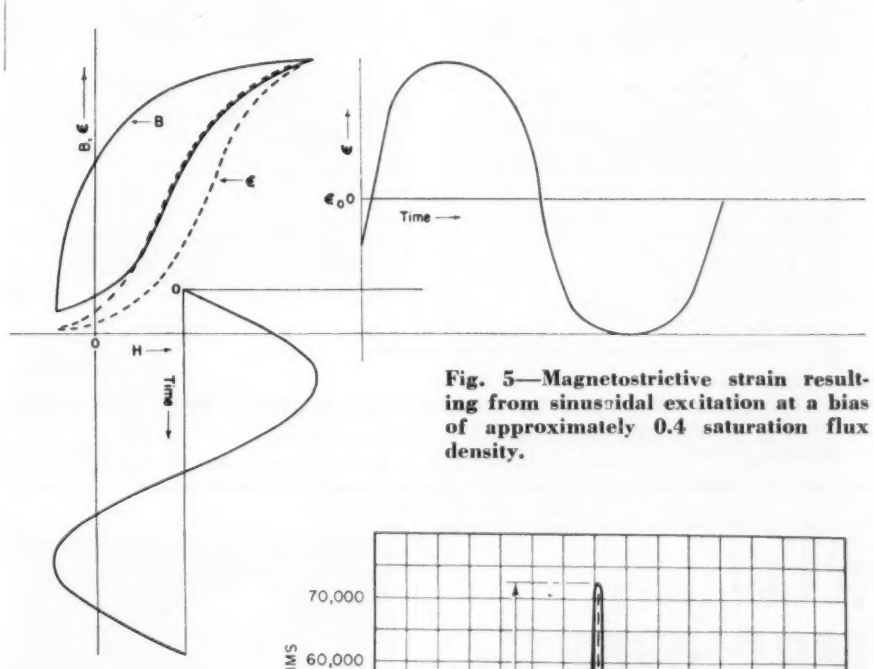
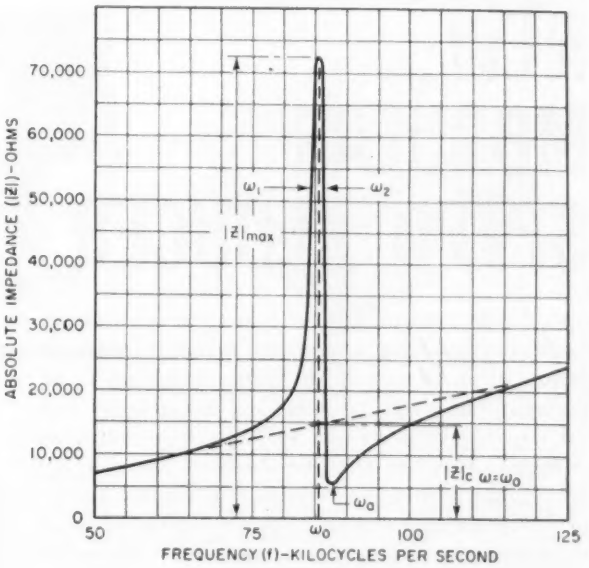


Fig. 5—Magnetostrictive strain resulting from sinusoidal excitation at a bias of approximately 0.4 saturation flux density.

Fig. 7—Impedance of N-50 ferrite rod as a function of frequency near the resonance point.



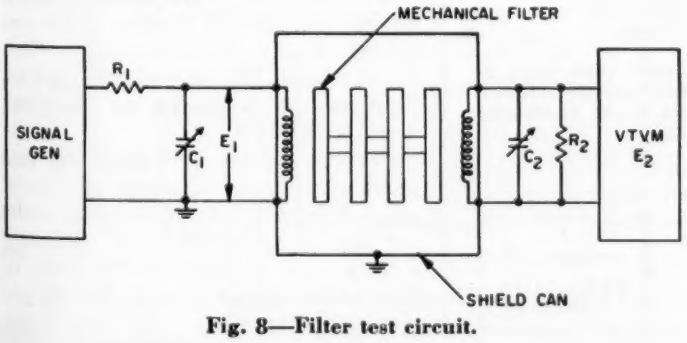


Fig. 8—Filter test circuit.

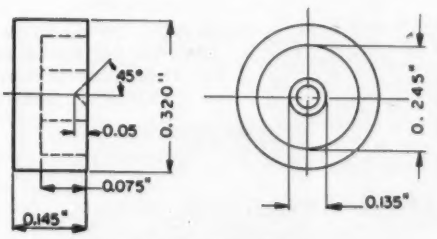


Fig. 9—Ferrite coil core.

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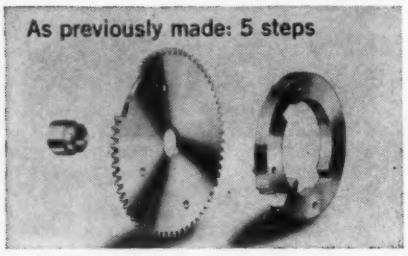

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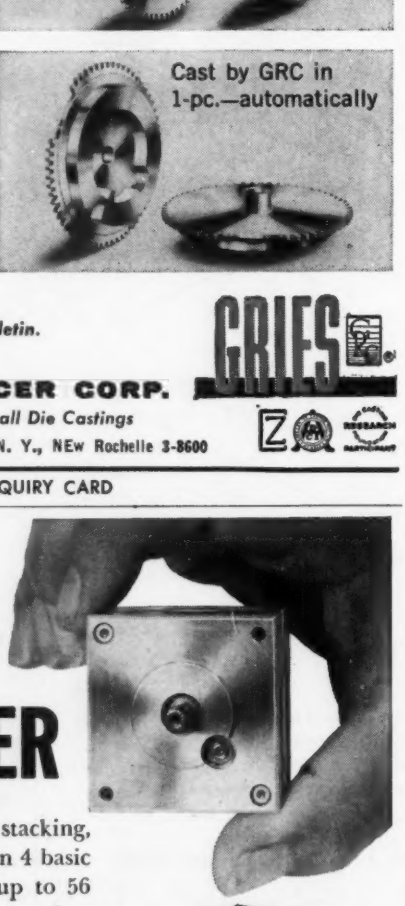

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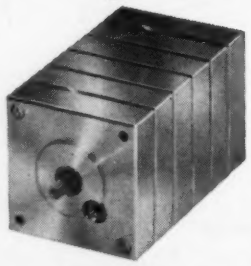

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MATERIALS

The impedance of a magnetostrictive vibrator near its resonance frequency is illustrated in Fig. 7.

The high electromechanical coefficient, k, of ferrites make them particularly suited for use in electromechanical filters. These filters employing a series of mechanically resonant elements coupled together are ideally suited for use in single sideband communication equipment. They meet precision performance requirements and are often smaller, lighter, and more rugged than equivalent L-C or crystal-type filters. Schematic diagram of such a filter is shown in Fig. 8.

It is an assembly of magnetostrictive ferrite discs resonant in the concentric shear mode fastened together with quarter-wave torsional couplers. The input and output coils are positioned in ferrite coil cores shown in Fig. 9.

In current designs, (See George, R. W., *RCA Review* 18, 186 1957) plans have been made to cement separate couplers between each disc. Here, magnetic bias is obtained from residual magnetism obtained by passing a current through a hole in the center of the disc. Excitation is obtained by application of the r-f field radially to the side of the disc. This makes it possible to use the end discs of the filter for efficient electromechanical transducers. Uniform circular bias and exciting field gives negligible excitation of spurious modes of response.

The transducers and the mechanical system have very low losses so that the important power losses must occur in the coils which couple to the transducers. If the coils are enclosed in low-loss ferrite cores, losses are minimized and the r-f field is concentrated in the transducer disc to obtain maximum electromechanical coupling to the energized portion of the transducer.

Different ferrites will, in general, be required for power transducers than for filter elements. To meet all demands, the ferrites listed in Table I have been developed.

As expected, the coupling coefficient, reversible relative permeability, and mechanical Q are strongly affected by the size of biasing field employed. This is demonstrated in Figs. 10, 11 and 12, respectively, which illustrate the properties of Kearfott's N-51 ferrite.

Ferrites for use in transducers employing moderate amounts of power ranging from 3.5 to 10 acoustic watts per square centimeter of radiating surface may be made in the form of thin walled cylinders or in the shapes shown in Fig. 13.

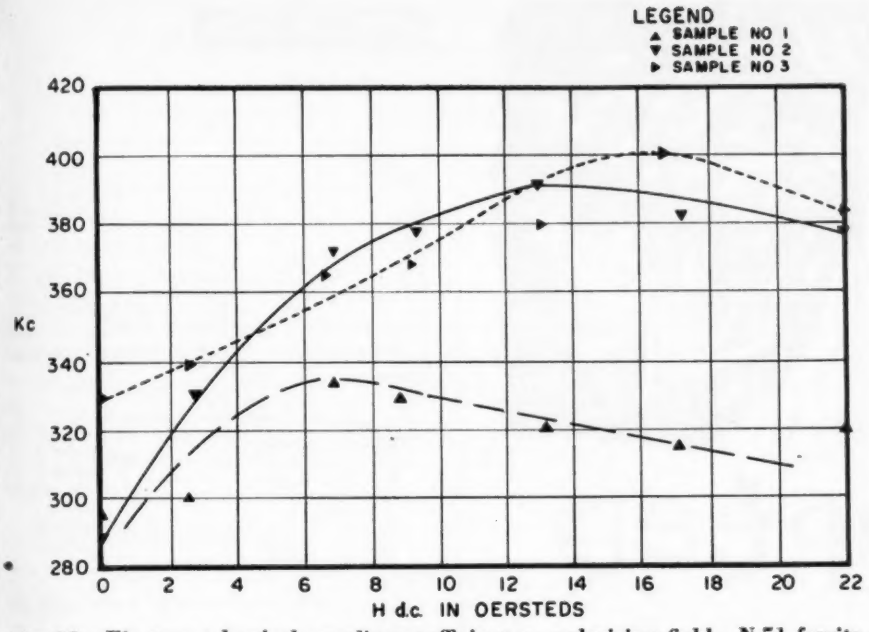

Fig. 10—Electromechanical coupling coefficient vs. polarizing field—N-51 ferrite.

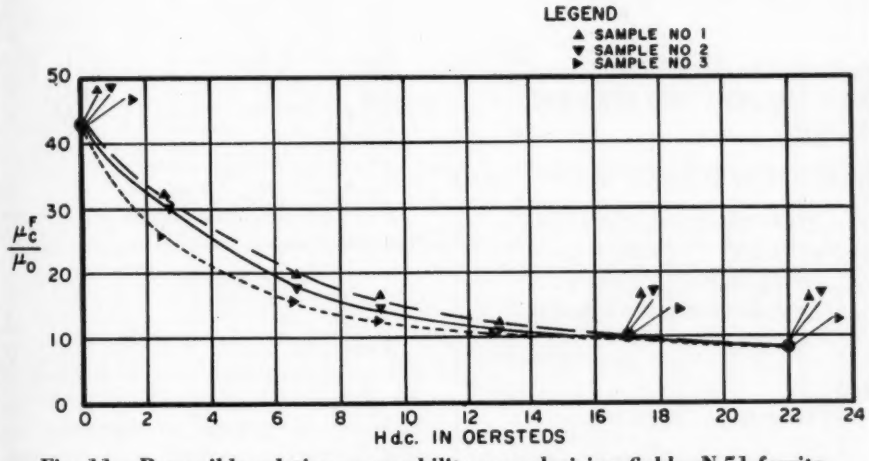

Fig. 11—Reversible relative permeability vs. polarizing field—N-51 ferrite.

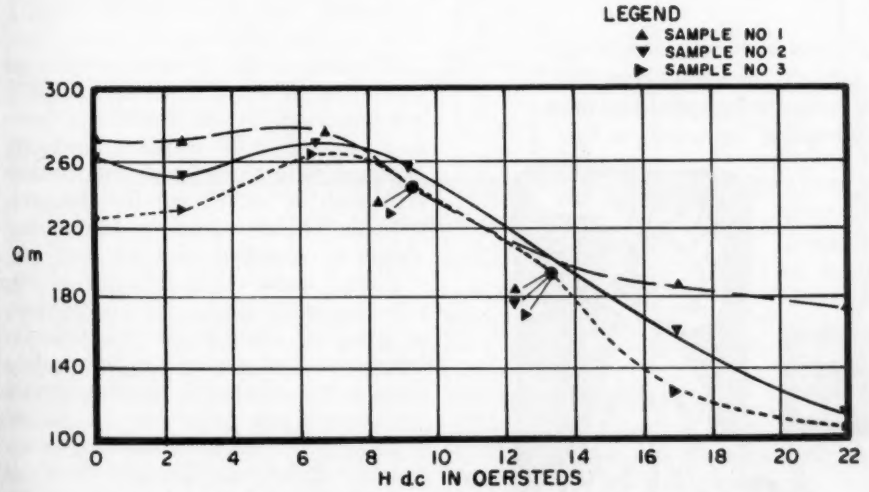

Fig. 12—Mechanical Q vs. polarizing field—N-51 ferrite.

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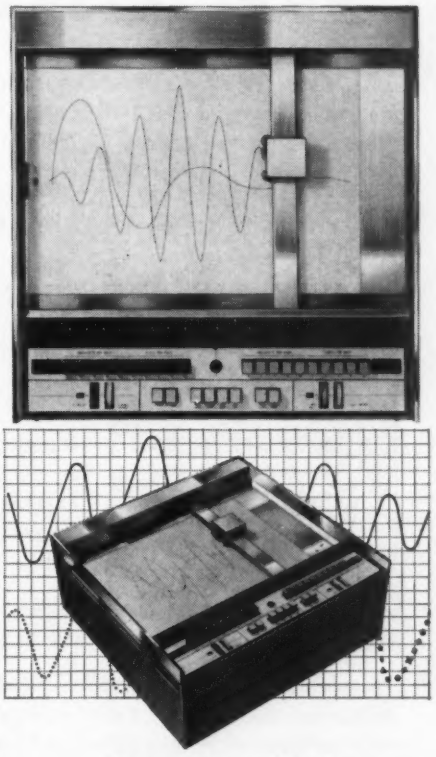

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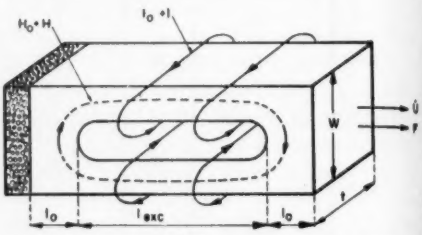
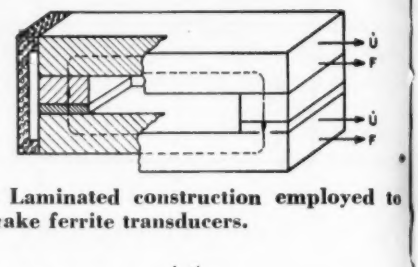
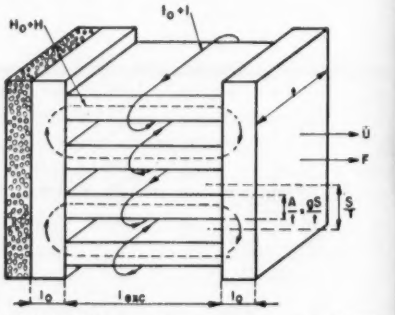


Ferrite cores for transducer applications.



Laminated construction employed to make ferrite transducers.



Multicellular constructon of ferrite transducers.

Fig. 13

The solid core, intended for low power applications, uses a d-c source for magnetic biasing. The transducers built up of sections of magnetostrictive ferrites cemented together employ pieces of ceramic magnets and couplers so that no d-c current for magnetic biasing is required.

Kikuchi reports (See Kikuchi, Y. J., *Acoustical Soc.*, Am., 29, 569, 1957) that ferrite transducers have been constructed with over-all efficiencies exceeding 85%. Efficiencies of 80% are common. It is desirable, therefore, to see how ferrite transducers compare with those made from materials such as nickel and the titanates.

Static characteristics of ferrites are shown in Figs. 14 and 15.

The dynamic characteristics of ferrites are quite likely not greatly lower than the static properties. Calculations show that even when large safety factors are employed, ferrites should be capable of radiating 15 to 20 acoustic watts/cm². However, present practice indicates a limit of 6 to 10 watts/cm² is a better design value for ferrite transducers.

TABLE I

Properties of Some Commercially Available Magnetostrictive Ferrites

	Kearfott N-50	Kearfott N-51	Curtiss Wright	Ferroxcube 7A	Ferroxcube 7B
Initial Permeability	34	91	--	--	--
Saturation Flux Density	2175	2540	2640	3270	3180
Remanence, B_r, gauss	1100	1725	1470	--	--
Density gm/cc	5.1	5.1	5.2	5.1	5.1
Curie Temperature (°C)	500+	500+	500+	500+	500+
Young's Modulus dynes/cm^2 10^{12}	1.65	1.60	1.67	1.70	1.7
Mechanical Quality Q_m	2800	260	800-2000	3000	3000
Reversible μ at Remanence	81	330	45	35	40
Magnetostriction Constant (dynes/gauss/cm^2)	-16,400	-45,000	-14,000	--	--
Electromechanical Coupling Coefficient	0.25	0.40	0.22-0.27	0.25 0.30	0.21 0.25

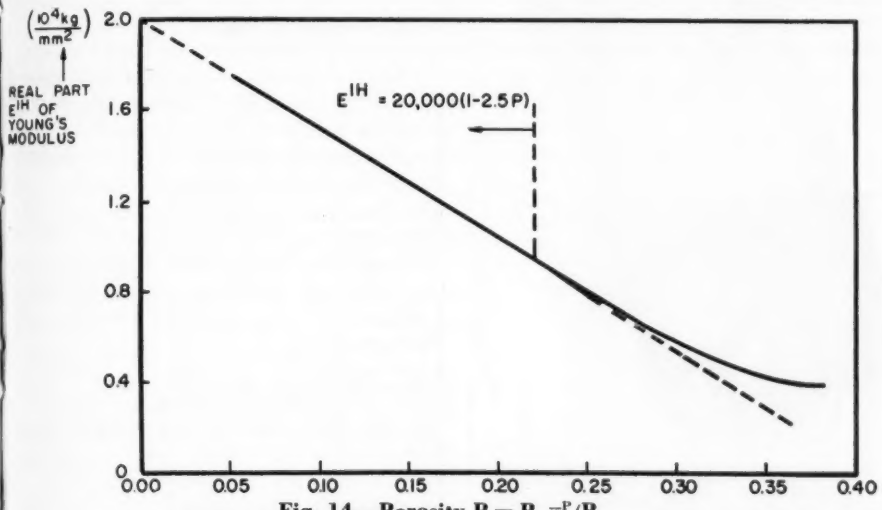


Fig. 14—Porosity $P = P_o e^{-bP}/P_o$

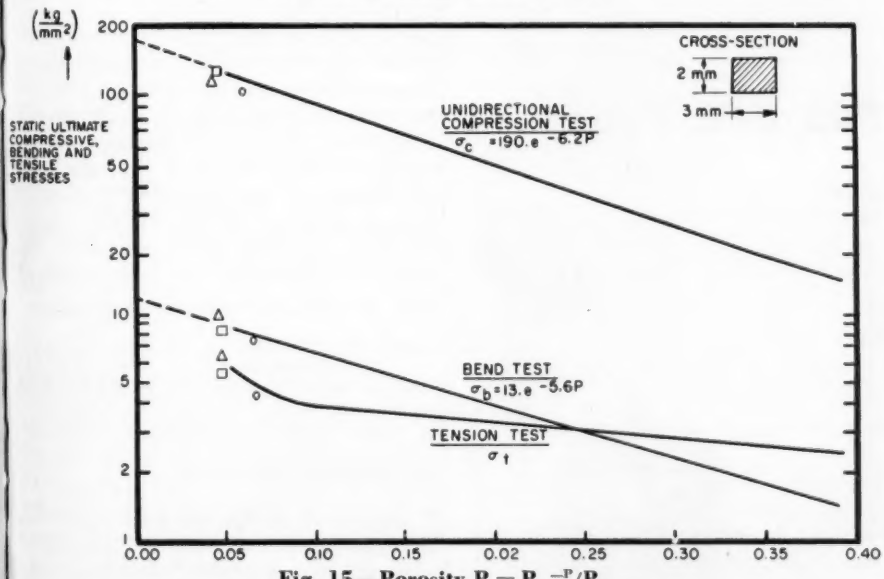


Fig. 15—Porosity $P = P_o e^{-bP}/P_o$

Ferrites have a coefficient of thermal expansion of about 10 x 10^{-6}/°C and have a much higher thermal conductivity than do the titanates. The pseudo fatigue limit of ferrites is therefore higher than that of the titanates but is lower than for laminated nickel. The resistivity of ferrites is high so ferrite transducers can be operated without the necessity of laminating even if the transducer is to be operated at very high frequencies.

Ferrites are chemically inert and cavitation effects are developed slowly. This makes it possible in many applications to place the ferrite transducer directly in the operating medium.

These considerations indicate that ferrite transducers have unique properties that will become increasingly important with time.

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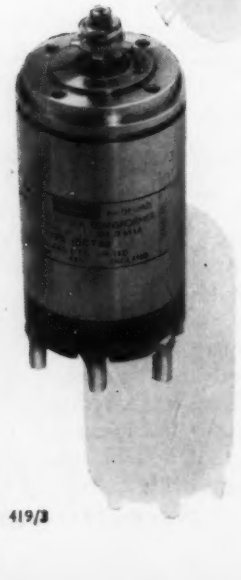

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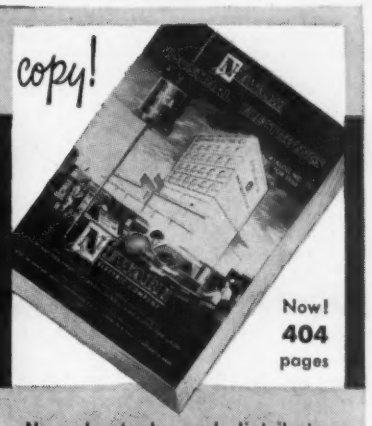

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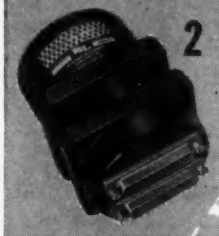

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Acceleration	45g for 2 seconds in six directions
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Insulation Resistance	100 megohms at 300 volts d.c.
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DESIGN TIME SAVER

SPECIFYING AN INSTRUMENT SERVOMECHANISM

This article is based on information being prepared for a special handbook section of a catalog on instrument servomechanisms by Superior Manufacturing and Instrument Corp., manufacturers of precision servomechanisms and electromechanical assemblies. We believe the timeliness and conciseness of this handbook information designed to assist the project engineer in specification and selection of servo packages will be a valuable reference to electromechanical engineers.

For the complete catalog, circle 78 on the inquiry card or write directly to the Company at 154-01 Barclay Ave., Flushing 55, Long Island, New York.

For the project engineer accustomed to assembling servomechanisms from component parts, packaged servos permit a real simplification in procurement. A single overall system specification, written directly in terms of desired performance, replaces a collection of component specifications individually more complex than the overall specifications. It is sufficient to specify only the overall package dimensions, the nature of the readout dials and output shafts, the input signal, the type of connectors, and the performance and environmental requirements. In brief, the entire servomechanism may now be treated as a black box. This approach relieves the designer from detailed subsystem problems and allows him to concentrate on the overall project.

INSTRUMENT SERVOMECHANISMS

Instrument servomechanisms are closed-loop electromechanical control systems in which the mechanical power output is relatively low or negligible. In such systems, speed and accuracy of response are the key performance factors.

By far the more important instrument servomechanisms are a-c, operated at some relatively constant line frequency. Therefore, reference in this article is primarily confined to a-c systems, although the information may directly apply to d-c systems.

To take full advantage of this black box treatment, it is important to consider overall performance requirements rather than individual component requirements. Table I lists items to consider and specify. Succeeding sections summarize important specification factors.

TABLE I

Packaged Servomechanism Requirements

Range of controlled variable	Nature of load
Static and dynamic accuracy	Mechanical requirements
Speed of response	Limiting dimensions
Stabilization characteristics	Environmental specifications

TABLE III

Comparison of Servomechanism Stabilization Techniques

Lead Network

Tends to accentuate input noise and residual voltages. Provides rapid response and good stabilization. Excellent in d-c servos, or a-c servos with constant carrier frequency.

Lag Network

Minimizes noise and residual voltages. Sluggish response to rapid input accelerations. Narrow bandwidth. Most used in d-c servos.

Tachometer

Extremely popular in both a-c and d-c servo-mechanisms. Provides excellent stabilization. Relatively costly and bulky. Introduces velocity lag during high speed tracking. Adds wiring complexity and residual voltages. However, does not subtract from slew speed or motor output capacity.

Inherent Motor Damping

For intermediate-to-low performance servos. Inherent damping increased by special motor design. Most suitable where miniaturization at low cost is prime objective.

D-c in Motor Winding

Easily provided by rectifier circuits in main phase, or, more commonly, by single ended driver tube with plate current through motor control winding. Decreases static accuracy slightly by introducing d-c slot effect. However, very economical and easily applied in proper circumstances. Motor dielectric strength must be adequate for B+ voltage plus a-c signal.

Inertial Damping

Flywheel on motor shaft, freely spinning, and coupled to rotor by eddy current drag. Damping provided only during periods of acceleration, with no reduction in output speed under constant velocity conditions. Independent of carrier frequency, and particularly effective in damping out non-linear oscillations due to backlash or stiction. However, emphasizes initial overshoot in step function response, critical damping being impossible.

Viscous Damping

Provided by rotation of conducting low-inertia drag cup fixed to motor shaft and rotating in field of stationary permanent magnet. Possesses general advantages of inertially damped units with exception that motor speed and output power are reduced by drag. Velocity lag occurs as in tachometer feedback damping. Critical damping feasible.

TABLE II

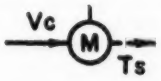
Symbols and Definitions

Motor

Ts = Stall torque, Oz-in
Vc — Control field voltage, Volts
D = Motor damping coefficient, Dyne-cm-sec/Radian
No = No load speed, RPM
J = Rotor inertia, Gram-cm^2
Km = Stall torque per control field volts, Oz-in/Volt
N = Speed, RPM
Tm = Time-constant, Seconds
Vco = "Starting" voltage, minimum control voltage to assure rotation, volts
α = Theoretical stall acceleration, Rad,Sec^2

RELATIONSHIPS

$No = (Ts/D) \times 6.743 \times 10^5$
$Tm = (Ts/J) \times 7.062 \times 10^4$
$Tm = J/D$

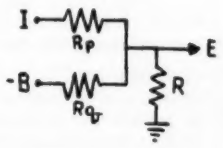


APPLICATION FACTORS

An a-c servomotor is a low inertia two-phase induction motor having a high resistance rotor to provide fast, linear response in a-c instrument servomechanisms. The main field is usually excited from the line while the control field is excited in time quadrature from the servo amplifier. Where special circumstances (such as certain magnetic amplifier circuits) prevent shifting the phase of Vc, a capacitor may be inserted to shift the main field voltage.

Summing Networks

E = P I — Q B
I, B, are voltage signals being compared
E is difference, or error signal
P, Q, are proportionality constants, depending on nature of network

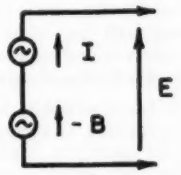


RELATIONSHIPS

(Parallel Summation)

$P = RRq/(RqRp + RRq + RRp)$
$Q = RRp/(RqRp + RRq + RRp)$

(Series Summation)
E = I — B (P, Q = I)



APPLICATION FACTORS

(Parallel Summation)

This permits summation of any number of inputs while maintaining a common ground point. However, summation accuracy depends upon the accuracy of summing resistors (Rp and Rq) as well as internal impedance of signal sources I and B.

(Series Summation)
This is a simple and direct summation of two or more voltages. The major disadvantage is that a common ground point for connection to the servo amplifier is not available except with the addition of precision isolation transformers.

Amplifier

Ka = Gain, Volts out/Volts in
Ka = Vc/E

APPLICATION FACTORS

Low output impedance is required for best motor damping. Phase shift must be relatively constant, even when saturation signals are applied at the input. Push-pull outputs may drive the servomotor control winding directly without d-c saturation of the motor core. Principal amplifier types are magnetic, transistor, vacuum tube, and combined types.

Gear Train

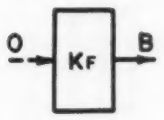
n = Speed reduction ratio = Output RPM/input RPM

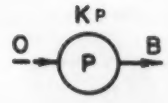
APPLICATION FACTORS

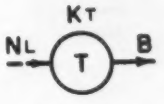
Gear trains should be designed for minimum inertia and low backlash, as both these items tend to introduce servo instability. In higher speed gearing particularly, small pinions and lightweight gears are suggested. Reductions at high speed meshes should be lower (2 to 3) than at low speed meshes where reductions of 5 to 6 are permissible. Anti-backlash gearing is suggested in high precision systems driving resolvers, and in two-speed synchro systems. Total reflected gearing inertia should generally be a small fraction of motor inertia.

Feedback Transducer

O = Output shaft position of servomechanism, Radians
B = Output voltage of feedback transducer, Volts
N_L = Output (or load) shaft velocity, RPM
Kf = Gain constant of shaft position to voltage transducer, Volts/Radian
Kp = Gain constant of feedback potentiometer, Volts/Radian
Kt = Gain constant (or gradient) of feedback tachometer, Volts/RPM
Kct = Gain constant of control transformer, Volts Radian

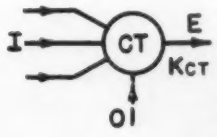






RELATIONSHIPS

1 Radian	=	57.30 Degrees
1 Degree	=	1.745×10^{-2} Radians
1 Radian/Sec	=	9.549 RPM
1 RPM	=	.1047 Radians/Sec



APPLICATION FACTORS

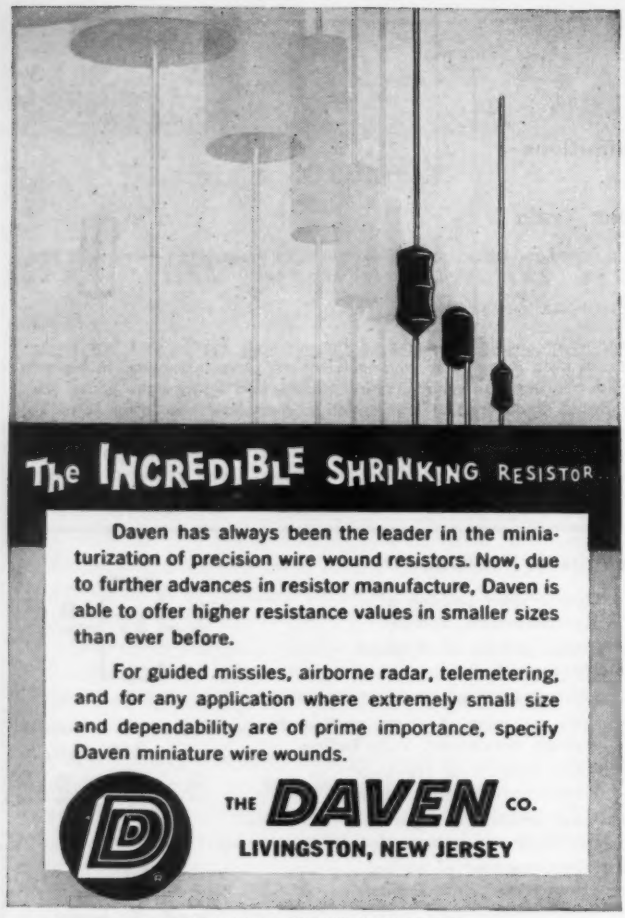
Feedback transducers convert servo output to a related electrical signal. There are a great variety to choose from, depending upon the function of output shaft position which it is desired to control. Angle is measured by potentiometer transducers, induction pickoffs, microsyns, resolvers and synchros, rotary differential transformers, and numerous other devices. Linear potentiometers and differential transformers convert linear displacements to electrical signals. A variety of tachometric devices apply where NL the output speed must also be controlled by the servomechanism. In all these devices, a proportionality factor specifies gain as required for servo calculations. In selecting transducers, however, a great many practical factors must be considered such as accuracy, size, reliability, resolution, residual voltages and price.

Load

FL = Load static friction, Oz-in
FLs = Load starting friction or "stiction", Oz-in
DL = Load viscous damping, Dyne-cm-sec/Rad
JL = Load inertia, Gm-cm^2
NL = Load velocity, RPM
AL = Load acceleration, Rad/Sec^2

APPLICATION FACTORS

The driven load may consist of output devices, potentiometers, counters, synchros, dials, or special mechanical loads. For servo applications, factors such as starting friction (affecting static accuracy), running friction, and inertia (affecting stability) are important. In many applications, an accurate representation of the load is very difficult to arrive at. Load friction can provide stabilization of a servomechanism, but because of its variable nature, must be relied upon only with caution.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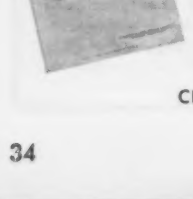

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TABLE IV

Actuator Selection Factors

CHOOSING THE SERVOMOTOR AND GEAR REDUCTION

1) In a gear train, the total apparent inertia must be determined at either the input (motor) shaft, or the output (load) shaft. To do this, add to the inertia at the shaft in question, the additional inertia reflected from the remaining shafts in the gear train. Reflected inertia from one shaft to another equals actual inertia at the first shaft multiplied by the square of the speed ratio of first to second.

Example: A gear train with a 20:1 reduction from motor to output shaft drives a load of 200 gm-cm^2. The reflected inertia at the motor shaft is 200 x $(1/20)^2$, or 1/2 gm-cm^2. If the reflected inertia of the gearing is negligible, the total apparent inertia at the motor shaft becomes motor inertia (gm-cm^2) plus ½. The apparent inertia at the load shaft equals this figure times 20^2 or 400.
Inertia is evidently much more significant at a high speed shaft, since the kinetic energy varies as the square of speed. A well designed gear train should contribute very little to total system inertia.

2) The torque required to accelerate an inertia is:
$T = J^{\alpha} \times 1.416 \times 10^5$, where
T = Ounce-inches
J = Gm-cm^2 (total apparent value)
$^{\alpha}$ = Radians/Sec^2

If the shaft is simultaneously rotating at N rpm, the power required for acceleration is:

$P = J^{\alpha} N \times 1.05 \times 10^{-8}$, where
N = RPM
P = Watts

The servomotor must be capable of supplying these watts.

3) If the load is negligible, the smallest available motor may be chosen. The gear reduction is based upon the required speed and/or acceleration of the output shaft.

4) If the load is primarily inertial and rapid acceleration is required, the servomotor must have adequate power output capacity to provide this acceleration. The gear reduction which best matches load to motor equals the square root of the ratio of load to motor inertia. For this reduction the maximum load acceleration equals one half the motor's theoretical stall acceleration divided by the reduction ratio. The motor may be selected and evaluated by simple trial and error, using these relationships.

5) For a primarily friction load, the gear ratio is selected to match the motor's maximum power output speed (approximately ½ the no load speed, for small servomotors) to the maximum specified speed of the load. Motor power must be ample to overcome load friction. (in the case of high starting friction, amplifier gain must be sufficient to assure required static accuracy.)

6) When the load combines friction and inertia, and speed and acceleration are simultaneously specified, the total power for driving and accelerating the load must be compared with the maximum power output of the motor. Load friction torque at the specified speed must be added to the acceleration torque as calculated from the formulas in item 2 to give the total load torque. This may be converted to watts at the given speed:
Watts = (1/1352) x RPM x Ounce-inches
The maximum motor watts must exceed this figure by an adequate safety factor. The gear ratio, motor to load, may be determined by assuming a series of values, and taking the ratio of motor power to required power from the above formula. The optimum gear reduction maximizes this power ratio.

7) Servomotors may be used requiring unbalanced powers in the individual phases. Thus, a much reduced control phase power, necessitating a small control amplifier, may mean a high torque per watt ratio with an increased main field power.

8) Servomotors are often combined with gearheads, slip clutches, spring-loaded gearing, viscous and inertial dampers, brakes, and similar electromechanical devices to make a versatile, easily applied assembly.

9) Life increases very sharply with any reduction in operating temperature. Motor bearings and lubricants are particularly sensitive to high temperature. The use of good heat-sinks, and the proper location of component parts are important factors in reducing temperature rise.

TABLE IV (*cont'd*)

GEAR DESIGN CONSIDERATIONS

1) Using a suitable safety factor — at least 35% — check the final selection of motor and gear ratio for adequate load driving power.

2) Since the gear ratio is generally not critical, a stage of gearing may occasionally be eliminated by using a somewhat lower reduction.

3) Relatively low reductions 2:1 are suggested in the fastest stage to minimize reflected inertia. Servomotor pinions cut into the shaft provide minimum inertia and should be used whenever possible.

4) Ratios in the slower stages are usually limited by the permissible size of the gearing from the packaging point of view. Ratios of about 6:1 are common.

5) Fine pitch gearing is recommended for instrument servos where backlash and accuracy are held to close tolerances.

6) Stainless steel gearing (such as a 416 pinion against a 303 gear) is particularly suitable for gearhead motors where high torque is required in a compact package. In high accuracy light weight packages driving light loads, stainless steel pinions drive aluminum gears.

7) Gearing tolerances affecting backlash and accuracy vary with location in the train. High speed shafts need not be as tightly controlled as the low speed output shaft, since errors are reflected inversely as the reduction ratio.

8) Spring-loaded gears located in the vicinity of the output shaft must be adequately loaded so as not to open up under the load driving torque, including sudden reversals. However, excessive spring-loading introduces friction in the servo as well as wear on the gearing.

9) Highest accuracy of positioning requires large gears in the low speed meshes.

For clarity and uniformity of notation, Table II has been prepared listing the important components of a-c instrument servomechanisms, defining standard symbols, significant relationships, conversion factors between common units, and application and selection factors.

Servomechanism Design Summaries I through III describe the more common servomechanisms accounting for nearly all applications. Performance factors are described in terms of the notation in Table II, which permits direct substitution in formulas. The analyses assume linear conditions; non-linear aspects of behavior must be evaluated separately.

STABILITY

Table III compares common techniques and lists selection criteria for instrument servomechanism stabilization. Stability problems become more critical for high accuracy or fast responding servomechanisms. Therefore, it is important not to overspecify these characteristics. Wide bandwidth, which permits response to rapidly varying inputs, also makes the servomechanism unduly sensitive to noise in the input signal. Also non-ideal mechanical features such as backlash, shaft play, and resiliences create serious stability problems in such servomechanisms.

SERVOMOTOR SELECTION

Table IV reviews the selection factors for the servomotor and the gear train reduction ratios. These depend upon load characteristics, input signal variations, and duty cycle. The choice of the motor establishes the overall size of the servo. A large motor for a heavy load needs more durable gearing and a larger driving amplifier and power supply. A poor choice of gear train reduction ratios can lead to excessive effective inertia, and to stability problems.

GEAR QUALITY

Table V supplements Table IV by tabulating important tolerances affecting gearing accuracy.

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Power Output	1/30 HP
Speed	20,000 RPM

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TABLE V

Classes of Precision Fine-Pitch Gears (AGMA)

Precision fine-pitch gears have three classes of accuracy namely, 1, 2, and 3 as shown in Table V (a).

Table V (a) Backlash For 20° Precision Fine-Pitch Gears

Class	Total Composite Error	Tooth-to-tooth Error
Precision 1	0.001 inch	0.0004 inch
Precision 2	0.0005 inch	0.0003 inch
Precision 3	0.00025 inch	0.0002 inch

Backlash For Fine-Pitch Gears

In addition to the three precision classes, fine-pitch gears are also classified according to backlash requirements as Class A, B, C, or D as shown in Table V (b).

Table V (b) Backlash For 20 Precision Fine-Pitch Gears

Class	Diametral Pitch	Backlash in Two Mating Gears of Equal Tooth Thickness Mounted at Nominal Center Distance
A	20 to 45	0.004 to 0.006
	46 to 70	0.003 to 0.005
	71 to 90	0.002 to 0.0035
B	20 to 60	0.002 to 0.004
	61 to 120	0.0015 to 0.003
	121 and finer	0.001 to 0.002
C	20 to 60	0.001 to 0.002
	61 to 120	0.0007 to 0.0015
	121 and finer	0.0005 to 0.001
D	No measurable backlash at any pitch	

The backlash values shown in the table are for the point of tightest engagement. When runout is present, the backlash at the low point of runout will be greater than that at the tightest engagement by 0.00073 inch for each 0.001 inch runout.

Tolerances For Fine-Pitch Gear Blank Elements

Tolerances for various elements of Precision fine-pitch gear blanks are given in Table V (c).

Table V (c) Tolerances For Precision Fine-Pitch Gear Blanks

Element	Precision Class 1	Precision Classes 2 & 3
Diameter of Bore	0.0005	0.0002
Taper of Bore*	0.0003 per inch of length. Max. .0 005	0.0002 per inch of length. Max. 0.0002
Concavity of mounting and registering surfaces	0.0005 per inch of radius for rigid blanks. 0.0003 per inch of radius for flexible blanks. Total not to exceed 0.0015.	
Convexity of mounting and registering Surfaces.	None for any class	
Lateral runout of spur and helical gears	.0 007 per inch of radius. Max. 0.0015	0.0005 per inch of radius. Max. 0.0005
Nonparallelism	0.0007 per inch of radius. Max. 0.0015	0.0005 per inch of radius. Max. 0.001

**No portion of the taper of the bore must exceed the bore diameter limit. Runout of outside diameter with bore: 20 to 39D.P., 0.002; 40 to 79D.P., 0.0015; 80 D.P. and finer, 0.001.*

TABLE VI

Nonlinearities in Instrument Servomechanisms

Motor Damping

This is a function of control voltage and speed. In determining operating speeds with or without external load, check manufacturer's performance curves. For stability calculations, the figure for damping should be no more than ½ the normal damping figure, since damping decreases at slow speeds and small control voltages. This reduced damping also affects velocity constant and time constant at slow speeds.

Backlash

By delaying gear train response, backlash within a closed loop tends to cause instability, particularly in high gain low friction systems. Backlash oscillations are characterized by a relatively high frequency, low amplitude buzz, and become difficult to control when the product of velocity constant and motor time constant exceeds about 3 or 4.

Saturation

This refers to stall torque or no-load speed limiting for large errors as a result of "saturation" in either the servomotor or the amplifier. The specified motor stall torque and no-load speed are conservatively viewed as saturation limits. A saturated servo-mechanism may not be analyzed by the common formulas. Slew speed, stability, and overshoot are best calculated on a "piece-wire" basis, assuming full saturation response until the error falls within the linear region. A satuated servo may overshoot seveal times as it nulls, even if damping is normally excellent.

Saturation is the principal limiting factor in attempting to compensate an inherently sluggish servo for inferior or misapplied components. The servo simply cannot handle the large corrections required.

Potentiometer Resolution

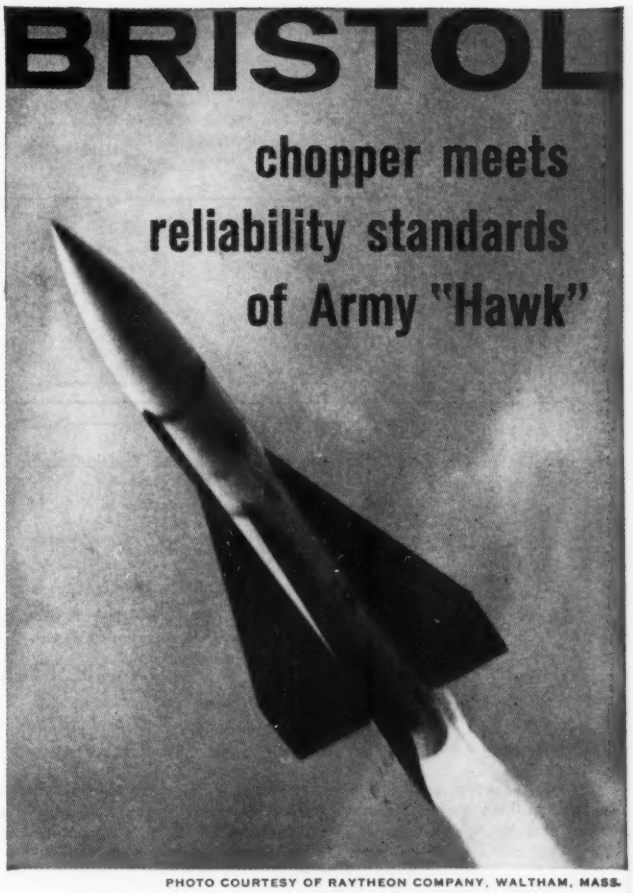
When a wire-wound potentiometer is used as a feedback transducer, the discreet-step nature of its output voltage vs position characteristic may introduce instability. In balancing out an input signal the potentiometer "interpolates" between adjacent steps, causing a high frequency oscillation, which is almost impossible to eliminate in high precision (high gain, low friction) systems except by improving potentiometer resolution. Multi-turn potentiometers driven at a higher speed than the load, provides a practical answer to most resolution problems. A good rule of thumb is that the servo must be unresponsive to signals of the order of magnitude of a single resolution step.

NONLINEARITY REQUIREMENTS

Common procedures of instrument servomechanism design usually assume linear behavior. However, nonlinearities do have a considerable effect on performance. To make allowance for nonlinearity, stability and performance safety factors of at least two-to-one are recommended. Provision for experimental adjustment of loop gain and stabilization is particularly important, since the designer need then only be sure of an adequate adjustment margin. Table VI lists the common nonlinearities encountered in instrument servomechanism design, describing their nature and effects.

CHECK LIST

Table VII is a comprehensive check list of factors to consider in specifying an instrument servo package. In particular instances, only some of these factors apply. However, a review of this table insures that nothing of significance has been omitted. The table discusses each selection factor briefly, indicating important variations.



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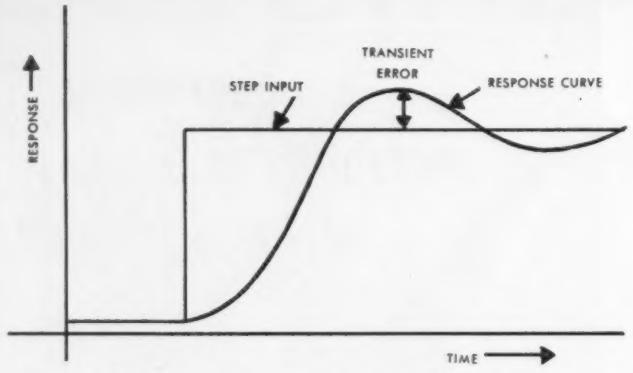
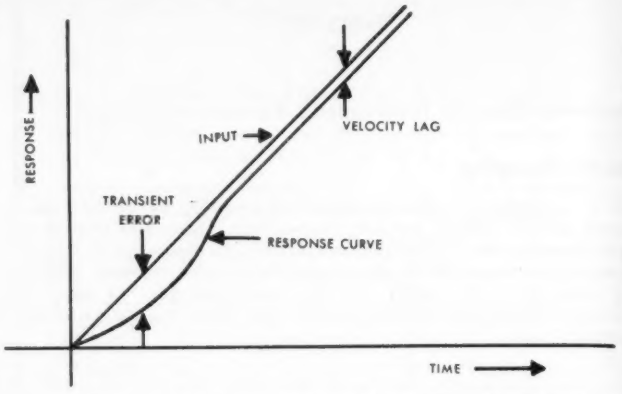


Response to step of poorly damped servomechanism. Oscillations occur at approximately the natural frequency.



Response of well damped servomechanism to velocity input.

TABLE VII

Check List For Specifying Packaged Servos

BASIC PACKAGE REQUIREMENTS

Standard vs Special Purpose Servo Packages

Standard servo package means lowest cost, best delivery, minor modifications and adjustments made economically to suit specific requirements. Special purpose packages more suitable where ultimate in compactness is required, substantial production anticipated.

Selection and Location of Amplifiers

Principal varieties: vacuum-tube, transistor, magnetic, and combined types. Transistor type, most efficient and compact, but costly especially for high temperatures. Magnetic amplifier rugged, reliable but relatively bulky. Temperature limits established by rectifiers. Amplifier within servo packages simplifies application, but reduces flexibility for other applications. Separate amplifier location determined by heat removal and cabling problems.

Standard and Semi-Standard Parts

Standard parts speed prototype delivery, lower initial cost. Production quantities determine advisability of engineering and fabricating special parts.

Power Supply Requirements

Voltage, frequency, regulation, waveform, ripple, power capacity. Compatability with package requirements. Frequency regulation particularly important where the servo incorporates precision magnetic components or stabilization networks.

Servicing, Spare Parts

Use of standard parts in construction. Complexity of adjustment procedures and variety of test equipment. Field vs. factory servicing. Spare parts stocking problems. Instruction and servicing manuals. Nature of the requirements. Military or industrial specifications applicable? Intended use. Breadboard, prototype, test purposes.

EXTERNAL PHYSICAL CHARACTERISTICS

Size Requirements

Design objectives, as well as maximum permissible limits. Extreme miniaturization adds markedly to cost of design, fabrication, and materials.

Type of Construction

Hermetic sealed, gasket sealed, dust cover, open breadboard. Hermetically sealed units not readily repaired or readjusted, but avoid corrosion, fungus, and arcing problems. Cooling of internal components is important.

Cost Factors

Compromise among cost and miniaturization, ruggedness, and special purpose design.

Mounting

Guide pins, mounting flanges, alignment tolerances, and related features to assure mechanical adaptability to existing equipment. Quick release fasteners, shock mounts.

Connectors

Type, configuration, and location of connector. Number and size of pins. Shielding. Nature of locking mechanism. Altitude requirements and high potential tests. Environmental requirements.

Appearance Factors

Nameplates and other markings. Style. Arrangement of dials, finish, color. Matching companion equipment may be a requirement.

Weight

Weight requirements and relationship to price. Miniature components. Use of light-weight materials. Closer design to minimize heavy wall sections.

Read-Out Requirements

Location, size and marking of read-out dials. CW or CCW for increasing dial reading.

Output Shaft Requirements

Location, dimension, radial and end play, material and hardness of output shafts.

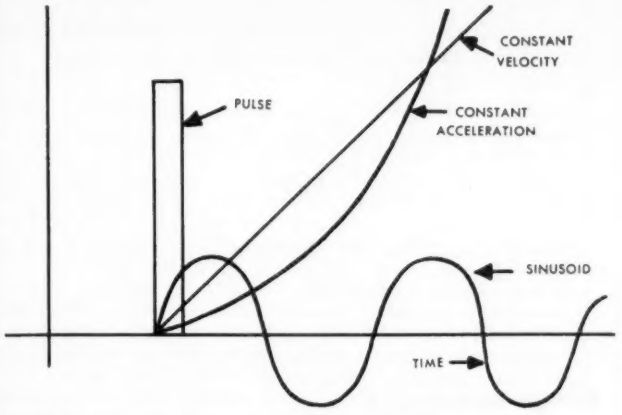
Pertinent Specifications

Standards and specifications applicable to the overall package, its internal construction, or any of its parts.

PERFORMANCE REQUIREMENTS

External Load

Static friction, viscous, and starting friction, inertia and mass of load. Alignment of load and servo shafts, and provision for coupling. Side and end loading requirements, peak load torques, backlash.



Types of input signals for servomechanism response testing.

Duty Cycle

Nature of variation of input signal. "On" time. Slewing vs. tracking. Transients.

Input Signal

Source of input excitation, potentiometer, synchro, etc. Voltage level, output impedance, description of input device. Ground points and common power supply requirements.

Output Signal

Level, scale factor, resolution, quality and accuracy. Grounds, output impedance, external electrical load.

Velocity and Acceleration Requirements

Definition of most severe combination of velocity and acceleration encountered in practice. This information plus nature of external load determine choice of servomotor and gear reduction ratio.

Static Accuracy

Positioning error; relationship to loop gain and fraction plus slot effect of motor, gear train and load. Accuracy of components vs. cost, quality of gearing, size and machining tolerances of precision mechanical parts. Backlash.

Dynamic Accuracy

Accuracy during tracking and transients. Nature of input signal variation. Type of servo, velocity lag. Acceleration lag. Choice of damping techniques with respect to dynamic accuracy. Specification of errors under clearly defined input conditions.

Maximum and Minimum Speeds

Slew speed during initial synchronizing. Synchronizing time from "worst" position. Minimum speed at which smooth tracking is required. Maxmum speed for accurate following.

Special Responses

Step displacement, velocity, or acceleration, sine wave input, random function input. Combination of inputs which most accurately simulates actual use.

Bandwidth and Time Constant

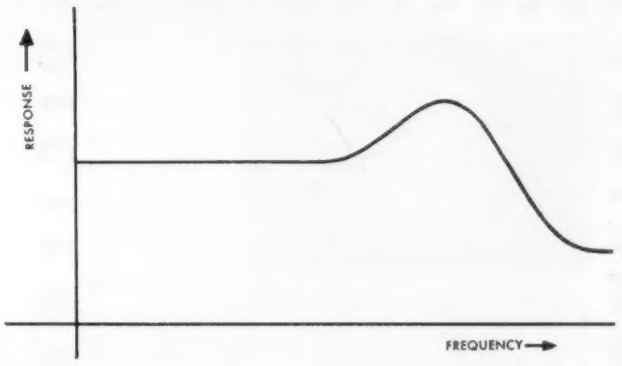
Bandwidth and time constant(s) for suitable following of rapidly varying input signals. Resonant peaks. Wide bandwidths mean critical tolerances, for example on backlash, to avoid oscillations due to residual time constants.

Damping Factor

Degree of damping vs. rapidity of response. For high natural frequencies lower damping ratios are permissible for a given settling time. Permissible amplitude and number of overshoots. Chatter due to backlash and potentiometer resolution.

Total Angular Travel

Required range. Limit stops vs. continuous rotation. Size, capacity and adjustment of limit stops. Ability to absorb impacts.



Servomechanism output amplitude response to sinusoidal input of constant amplitude and adjustable frequency. Peak response occurs in vicinity of natural frequency.

INTERNAL DESIGN CONSIDERATIONS

Replacing Components

Removing and replacing components. Tools. Soldering Plug-in vs screw type connections. Access to parts. Interchangeability of components. Readjustment, special equipment.

Zeroing and Alignment

Ease of zeroing and alignment. Tools or equipment required. Permanence of adjustments.

Slip Clutches

To prevent damage in low speed end of high reduction ratio gear trains. Safety precautions during transients or faulty operating conditions. Setting the clutch slip torque.

Pinning Gears

To avoid loss of accurate shaft alignment during normal use and after occasional impacts. Mechanical assembly must, however, include provision for re-orientation of components for adjustment of zero or other reference position.

Lubrication

Permanence of lubrication. Provision for relubrication. Quality of lubricant and temperature range. Shelf life.

Class of Insulation

Dependent on temperature range, including temperature rise of components, particularly under high altitude conditions.

Precision and Mesh of Gearing

Gearing accuracy and backlish are determined by the accuracy required of the servo loop as well as stability requirements. Adjustable vs. fixed centers. Anti-backlash gearing, effects of wear, and cost factors. Size of gearing permitted by overall dimensions.

Component and Part Specification

For more critical, less well-understood parts. Specialized experiences with certain items may lead to individual specifications.

General Environmental Design Features

Military vs. non-military.

Special Environments

Temperature extremes, random or complex wave vibration, acoustic noise, neutron radiation, may suggest detailed specifications.

Basic Servo Type

Synchro positioning system, tachometer, feedback, velocity or integrating servo, two-speed synchro system, etc.

Pitch of Gears

Pitch determined by accuracy, load capacity, pinion O.D., and reduction ratios.

Gear Materials

Pinion and gear material combination for long life. Stainless steel vs. brass (or aluminum for light weight). Hardened steel for maximum life, severe loads.

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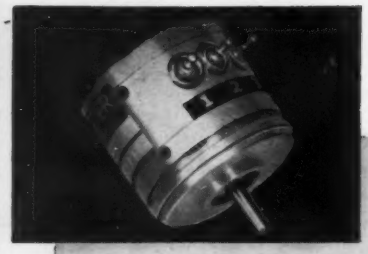

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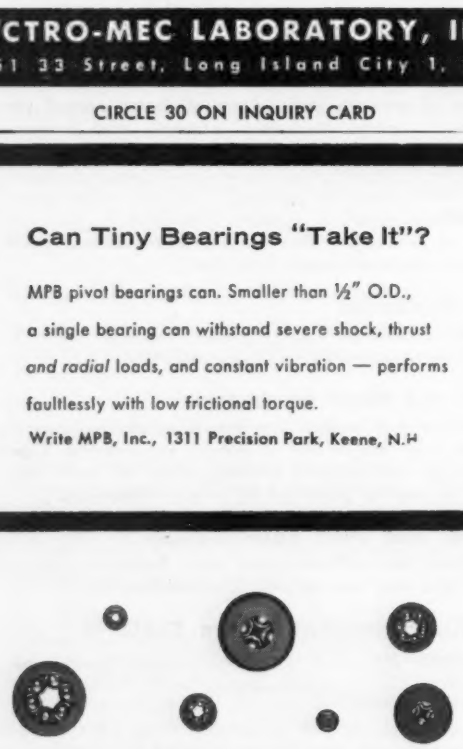

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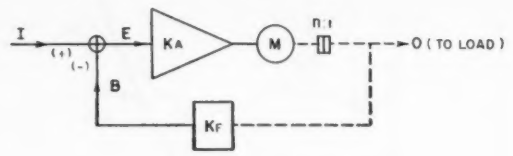

Fig. a

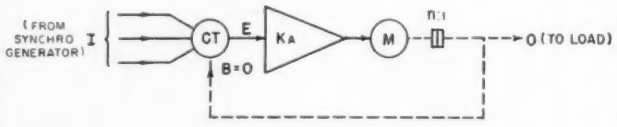

Fig. b

Design Summary 1

TYPE OF SERVO

Positioning servomechanism, moderate accuracy.

SCHEMATIC DIAGRAM

Fig (a) Positioning servomechanism, general arrangement.
Fig. (b) Positioning servomechanism using synchros.

SPECIAL CONDITIONS

Load neglible, gear ratio selected on basis of required slew speed.

PERFORMANCE CALCULATIONS

Loop gain, Kv, sometimes called the velocity constant, equals servo velocity per unit error, in consistent units. Kv may be expressed as the ratio of transducer velocity (volts/sec) to volts error signal, and has the dimension of 1/sec. Attenuation, Q, in the feedback summing circuit may be lumped in with the factor Kf.

$Kv = 1/sec = (Ka\ Km\ Kf / Dn) \times 7.062 \times 10^4$, units defined in Table II.

Velocity lag (tracking error at uniform speed) equals output shaft speed divided by Kv, in consistent units. For output speed in radians (or degrees) per second, velocity lag will be expressed in radians (or degrees).

Static error (due to servomotor friction and slot effect) equals Vco/Ka, expressed in volts at the servoamplifier input. Slew speed = No/n RPM

Stiffness, K, is the "spring constant" or torque per unit deflection at a given shaft. At the output shaft,

$K_{output} = Kf\ Ka\ Km\ n$ oz-in/radian, or $1.745\ Kf\ Ka\ Km\ n \times 10^{-2}$ oz-in/degree.

K at the motor shaft is,

$K = (Kf\ Ka\ Km/n) \times 7.062 \times 10^4$ dyne-cm/radian

Kv (velocity constant) $= K/D = (Kf\ Ka\ Km/Dn) \times 7.062 \times 10^4$

Theoretical stall acceleration at the motor:

$\alpha = (Ts/J) \times 7.062 \times 10^4$ rad/sec^2

At the load, this figure is divided by n.

Servo damping may be expressed in a number of different ways in terms of the quantities listed above and in Table II. The dampening factor, ζ, is given as:

ζ = actual damping/critical damping

$\zeta = D/[2(KJ)^{1/2}] = 1/[2(Kv\ Tm)^{1/2}]$

K = stiffness at motor shaft (dyne-cm/rad)
Tm, D, and J are defined in Table II.

The natural frequency of the servo, ω_n(rad/sec.), is given by the expressions:

$\omega_n = (K/J)^{1/2} = (Kv/Tm)^{1/2}$

Settling time, after a transient, for a given damping factor ζ, is inversely proportional to ω_n. Therefore, servos with high natural frequencies may be permitted somewhat lower values of ζ. For a $\zeta = 0.6$, the initial overshoot to a step function is approximately 15%, and the peak of the frequency response characteristic has a "gain" of about one to two db.

Design Summary 1 *(cont'd)*

REMARKS

"I" is an electrical input balanced out by the feedback transducer, which converts output angle, "O", to a similar voltage. A resistance potentiometer is the commonest variety of feedback transducer. Its successful application requires consideration of its resolution characteristic, resulting from the finite voltage steps as the slider moves from one wire to the next, see Table VI.

The output transducer and summing network are conveniently combined in the control transformer, the receiving end of a synchro-servo system, Fig. 1(b). The control transformer's angular input is derived in electrical form from a synchro generator or differential generator, and develops an output signal (error) proportional to the sine of the difference between its electrical input angle, I, and its shaft position, O. The formulas derived above for the general feedback transducer positioning system apply directly, where

$K_f = 57.30 \times$ volts/degree gradient of control transformer.

This type servo is remarkably suited for remote angle transmission as a result of the 3-wire symmetry of its input, and the consequent insensitivity to stray capacitance, inductive pick-up, and grounding problems. Synchros operate at high speeds have longer life, are free from noise and resolution problems, and possess superior accuracy to most other angle transmission means.

ILLUSTRATIVE EXAMPLE

The design summaries at the end of the article are completely worked out typical design problems illustrating the points brought out in the tables. Figures in these summaries show the final servomechanism, as well as wiring diagrams and performance data.

To illustrate the design procedures outlined above, consider a two-speed synchro repeater meeting the following specifications:

Two-speed positioning servomechanism with 36:1 ratio

Static accuracy	6 minutes
Slew speed	12 rpm
Tracking speed (maximum)	10 rpm
Tracking speed (minimum)	⅛ rpm
Power available	115 volts, 400 cps
	28 volts, d-c

The repeater is to accept inputs from a pair of size 15 BuOrd 115 volt, 400 cps synchro generators. The driven output member is a size 15 CT whose input and output circuits are not part of the servo loop but rather are connected to their own separate external circuits. The package is to meet the general requirements of MIL-E-5272A and at the same time to constitute a compromise between miniaturization and low cost. Details relating to mechanical configuration, read-out dials, etc., are not listed here although they must be considered in the package design.

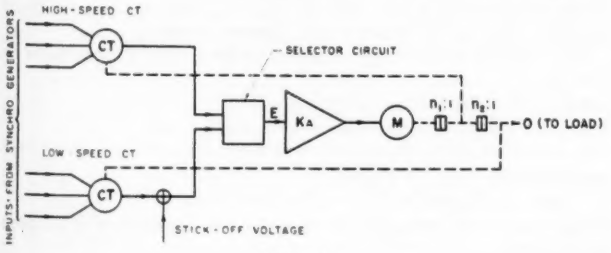

Fig. 1.

Solution

The configuration of the servomechanism is shown in Fig. 1, and is essentially identical to the configuration shown on Servomechanism Design Summary 3. To match the transmitting synchros, BuOrd size 15 CT's are used. Because

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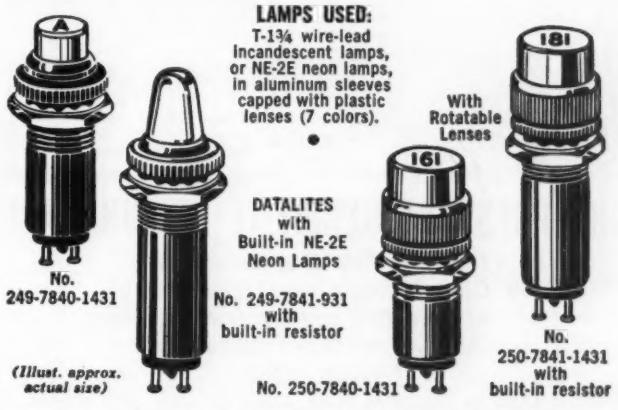
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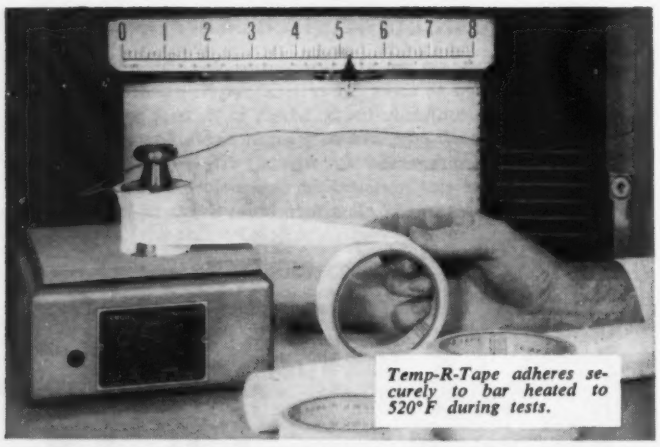

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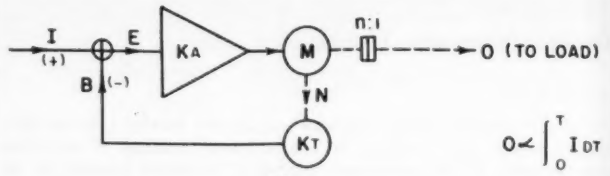


Fig. a.

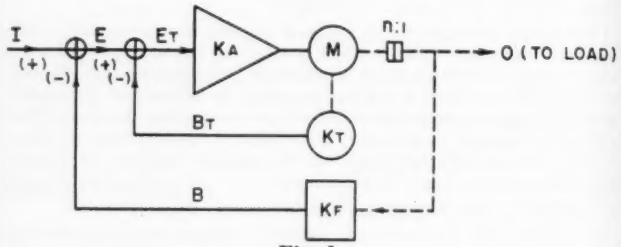


Fig. b.

Design Summary 2

TYPE OF SERVO

Velocity or integrating servomechanism, velocity damping.

SCHEMATIC DIAGRAM

Fig. (a) Integrating servomechanism.
Fig. (b) Velocity damped servomechanism.

SPECIAL CONDITIONS

Load negligible. Gear ratio selected on basis of integration scale factors and maximum value of integrated voltage.

PERFORMANCE CALCULATIONS

Output speed adjusts such that tachometer output B equals input signal I minus the error.

$$N K_t = I - E$$
$$N = (Ka\ Km\ E/D) \times 6.743 \times 10^5 \text{ RPM}$$

Eliminate E and solve for N

$$N = (6.743 \times 10^5\ Ka\ Km\ I) / (6.743 \times 10^5\ Kt\ Ka\ Km + D)$$

The 6.743×10^5 factor results from the use of popular but inconsistent units. If Kt is redefined in new units as Kt′ (volts/rad/sec), Km′ (dyne-cm/volt), and output speed, N′ in radians/sec, then

$$N' = (Ka\ Km'\ I)/(Kt'\ Ka\ Km' + D)$$

For very high loop gain, Ka,

$$N' = I/Kt'$$

so that N′ (rad/sec) is directly proportional to input volts and inversely proportional to the tachometer gain constant Kt′ (volts/rad/sec) including attenuation if any in the summing network.

For transient analysis the transfer function of the servomotor is given as:

$$pO/E = (Km'\ Ka/D)/(1 + pTm),$$

where p = differential operator d/dt and pO = N′.

This transfer function relates output velocity, pO (radians/sec) and the error voltage, E. In mixed units,

$$N/E = [(Ka\ Km/D) / (1 + pTm)] \times 6.743 \times 10^5$$

where speed is in RPM, and Km in oz-in per control volt, a constant of the motor.

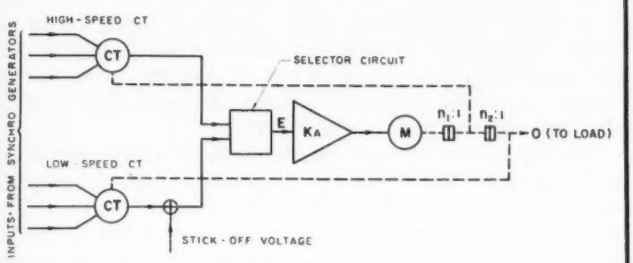
The closed loop transfer function for the velocity-damped servo is given as:

$$pO/I = [Km'\ Ka/\ (D + Km'\ Ka\ Kt')] / \{1 + p\ [Tm\ D/(D + Km'\ Ka\ Kt')]\}$$

This is identical in form to the transfer function of the servomotor alone in which damping has been increased by Km′ Ka Kt′. That is, dynamically, tachometer feedback around a motor loop is exactly analogous to increased motor damping.

Design Summary 2 *(cont'd)*

The minimum speed at which the servo will follow at all is given as:
Min. RPM = Vco/(Ka Kt)
where Vco is the motor starting voltage. For smooth accurate tracking, the minimum design speed should be several times this value. Variation in the in-phase component of tachometer output as a function of shaft position will modulate shaft speed noticeability at very low levels.



Design Summary 3

TYPE OF SERVO
Two speed synchro transmission system.

SCHEMATIC DIAGRAM
Two speed synchro system repeater.

SPECIAL CONDITIONS
Pair of control transformers driven from pair of generators for high precision positioning system.

PERFORMANCE CALCULATIONS
Two speed synchro systems are used where positioning accuracy to several minutes is required consistently, and over long transmission distances. A pair of high speed synchros geared up from the transmission shaft performs the tracking function such that accuracy at the slower output shaft approximates system accuracy divided by synchro speed ratio. In high precision systems using accurate synchros, error limits are determined by the gear train.

The principal problem is ambiguity, which occurs as a result of the large number of incorrect stable null positions which the high speed synchro channel may assume, only one of which corresponds to a correct output shaft position. This is explained below.

In normal tracking the servomechanism behaves exactly like a single speed transmission system in which the high speed CT controls circuit response. The low speed CT, coupled to the driven load, is considered part of the load. The low speed CT only enters the circuit when a large error signal occurs, at which time the selector circuit transfers the amplifier input fom the high speed to the low speed CT, which the servomechanism drives to the vicinity of a null. When the error is sufficiently low, the selector circuit switches back to the high speed CT, and tracking continues as before.

For even values of the speed ratio, n_2, a stable null occurs when the low speed CT is displaced 180° from its correct position. This ambiguity is eliminated by inserting a "stick-off" voltage in series with the low speed CT output and rezeroing by a small displacement of the low speed CT from its correct null position.

Some important application factors are listed below:

- The stick-off voltage = 90 × (volts/degree of synchro)/(synchro high to low speed ratio).
- The high-speed CT may have its output attenuated to avoid excessive loop gain and a stability problem.
- Accuracy = high speed synchro system accuracy divided by gear ratio, plus gear error.
- 36:1 is the most common speed ratio, n_2. Output dials on the low and high speed shafts may read 360° and 10° full scale respectively.
- Accuracies to 1 minute are feasible where accurate spring-loaded gears of sufficient diameter are employed.
- Design is based primarily on the high speed channel.
- Semi-conducting diodes are commonly used as switching circuits, exhibiting good fast switching, compactness, and excellent reliability.

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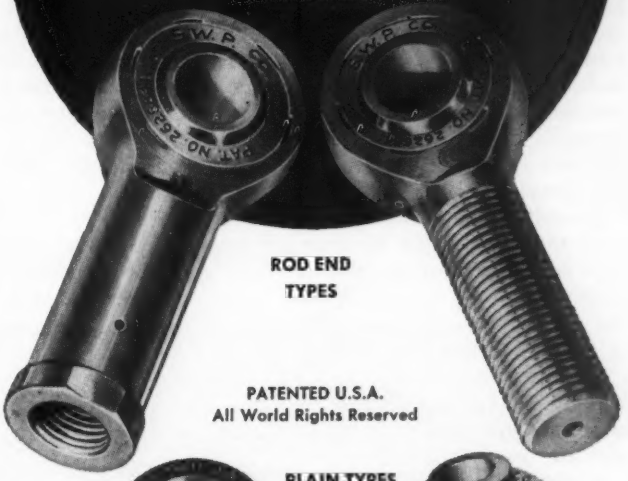

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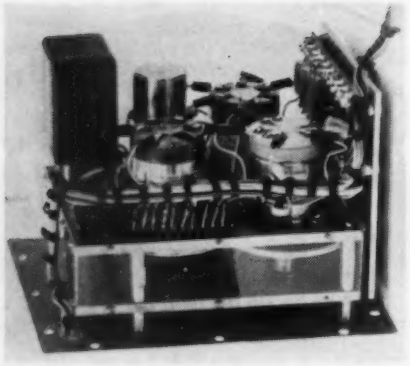

Fig. 2

load friction and inertia are very light, gear reduction ratios are chosen on the basis of speed requirements rather than power or acceleration requirements. A small servomotor should have adequate output capacity. The BuOrd size 11 servomotor is chosen since it is a proven, inexpensive, and generally available frame size, smaller than the size 15 synchros in the package. A small motor would hardly reduce the overall package size.

Described on Servomechanism Design Summary 3, this type servomechanism is analyzed by consideration of the high speed synchro channel. The slew speed of 12 rpm, corresponding to a large amplifier error signal, must match the motor slew speed of 6000, indicating a gear reduction of 500/36 from motor to high speed synchro.

Because there are no accuracy requirements during tracking, tachometer damping is suggested. Size 11 combinations of servomotor plus damping tachometer as a single integral unit are readily available.

Static accuracy requirements in a two-speed synchro system are generally determined by the precision of the gear train, since synchro and servo errors are divided by the synchro speed ratio, in this case 36:1. For the synchros of this example, the sum of generator and CT error in the high speed channel is about 10 minutes or 10/36 minutes effectively, a negligible quantity in comparison with the permissible 6 minutes of total error.

In establishing amplifier gain, assume the servomechanism positioning error is to be held, to appproximately the same limits as the synchros', namely about 10 minutes at the high speed shaft. Since motor starting voltage, the minimum voltage at which an error will be corrected, is specified as 3 volts, and the high speed CT provides 1 volt per degree of error the servoamplifier must provide 3 volts for an error of 10 minutes corresponding to 1/6 volt. This gain is so low, even with a factor of safety of two or three, that it becomes apparent that with a reasonable gain figure, servo static accuracy errors become trivial.

The big source of error in this type of servomechanism is in the gear train. Error components result from inaccuracies in gear profile, and in location of centers. The former contribute to positioning inaccuracy, while the latter causes backlash. Anti-backlash gears are essential, especially in the lower speed gears, if highest accuracy is to be achieved. Profile errors are minimized by accurate machining of gear blanks and cutting of teeth, and are smallest in large gears. System accuracy, in the last analysis, sets the size of the gears, and indirectly the size of the package. The actual servomechanism, incorporating a transistor amplifier operating from the 28 volt d-c supply, is shown in Fig. 2. Factors relating to damping, stability, and other aspects of performance are readily analyzed by reference to Design Summary 2 on tachometer damped servos.

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Input Power (total) 3.8 watts Stall Torque 18 oz in min. Max. Weight 29 gms.	Input Power (total) 3.2 watts Stall Torque .3 oz in min. No Load Speed 6200 rpm min.	Generator: Input Voltage 10 v Output Voltage 0.13 v/1000 rpm max.	Output Power 4.0 watts No Load Speed 20,000 rpm Input Voltage 28 v DC	Linearity .5% Null E at EZ .015 v Phase Shift 15 deg. lead	Accuracy 7' error max. Null 30 mv max. Phase Shift 9.5 deg. lead	Accuracy 30' max. error spread Torque Gradient 2200 mg-mm/deg. Input Power .34 watts	Accuracy 7' error max. Null 30 mv max. Phase Shift 8.5 deg. lead	Accuracy 7' error max. Null 30 mv max. Phase Shift 9 deg. lead	Accuracy 7' error max. Null 30 mv max. Phase Shift 11 deg. lead

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DESIGN TIME SAVER

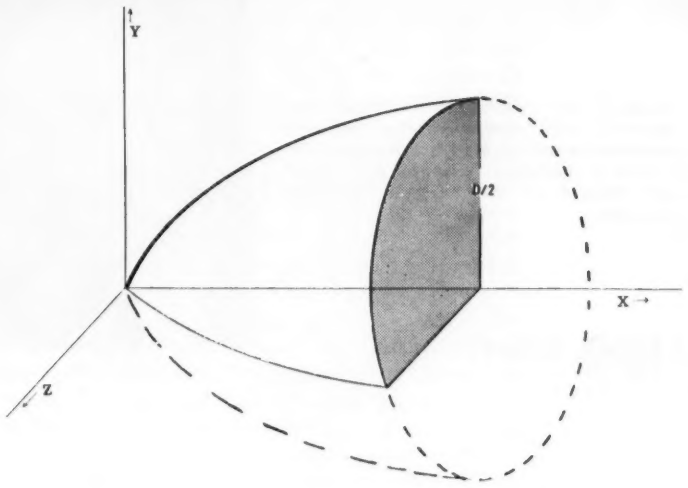


Fig. 1—Paraboloid of revolution. The diameter of the base is D.

By Daniel Levine,
Consulting Engineer, Glendale, Arizona

MOMENTS OF INERTIA OF A PARABOLOIDAL SHELL

In the analysis of the antenna drive for a parabolic reflector, the chief problem is the moment of inertia of the paraboloidal shell itself; that of the feed assembly and counter weights usually can be approximated without difficulty. Here is a graph that provides the necessary information concerning the reflector.

Many radar antennas employ paraboloidal reflectors for formation of thin pencil beams of radiation. When antennas of this nature are rotated with varying angular velocities to scan a region of space, it is necessary to determine the moments of inertia of the complete structure in order to compute the drive power required. These quantities include the effects of the primary feed and of any other appendages and braces on the rotating assembly.

For design purposes the initial problem is to obtain the moments of inertia of the paraboloidal shell alone about a convenient set of axes. Thus, the moments of inertia of the paraboloidal shell of Fig. 1 about the coordinate axes are

$$I_y = I_z = mf^2\{3/7[(\alpha^7-1)/(\alpha^3-1)]-1\}$$

$$I_x = 4mf^2\{3/5[(\alpha^5-1)/(\alpha^3-1)]-1\}$$

where

$$\alpha \equiv [1 + 1/16(D/f)^2]^{1/2}$$

m = total mass of the shell
f = focal length of the paraboloid
D = diameter of the aperture

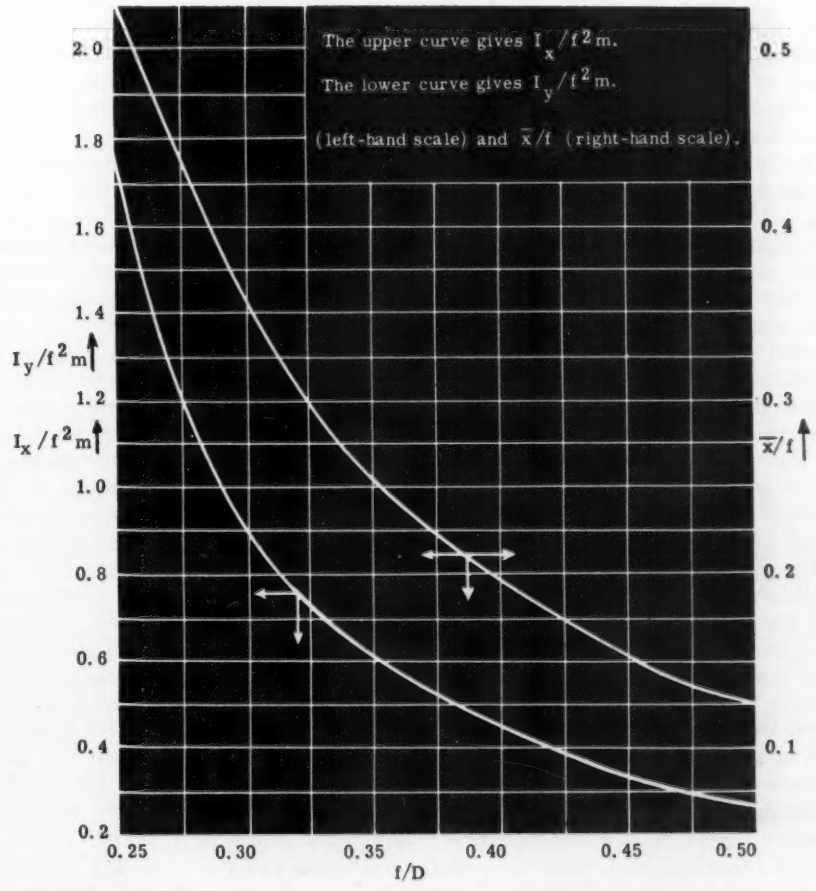


Fig. 2—Moments of inertia and center of mass of a paraboloidal shell.

The center of mass is located at

$$\bar{x} = f\{3/5[(\alpha^5-1)/(\alpha^3-1)]-1\} = I_x/4mf$$

$$\bar{y} = \bar{z} = 0$$

while the mass is $8\pi\rho f^2 (\alpha^3 - 1)/3$, where ρ is the surface density. If the paraboloidal is of an open-mesh type or has uniform ribbing to reinforce it, surface density can represent an average value.

These functions are plotted in normalized form in Fig. 2 for $0.25 \leqslant f/d \leqslant 0.50$. A typical value of this ratio for antenna design is f/D = 0.33.

Robert R. Lent, formerly an Air Force Major associated with administration of research and development at Air Force Headquarters is now a marketing executive and officer and director of the Strategic Industries Association.

GOVERNMENT EROSION OF THE PATENT RIGHT

The nature of the patent grant from the point of view of the government and the major weapon systems contractor suggests quite clearly that patent matters are minor matters in the conduct of their activities. Their remarks, with those of many other government officials with whom I have discussed the subject in Washington, imply strongly that their major aim is to insure that patent matters in no way impede their work and I am emboldened to charge that, at least privately, the defense agencies of the Government hold the patent grant as merely an obstacle to their day-to-day activities, one to be avoided altogether if possible and to be at least neutralized prior to initiation of the classic entanglement of patent litigation.

I do not charge the defense agencies with illegality in their present administration of their procurement regulations and, assuredly, the prime contractors are innocent in intent in their function as agents of the Government. The purveyor of the patent grant is the Congress of the United States and it is at its door that the charge of dilution of constitutional rights must be laid; but my own personal experience in Washington convinces me that the instigator, energetic persuader and recipient of privilege in this erosion of our liberty is the Department of Defense and its associated agencies, specificially the Atomic Energy Commission and the National Aeronautics and Space Administration.

Our Constitution, Article 1, Section 8, says: "Congress shall have the power . . . to promote the progress of science and the useful arts by securing for limited times to authors and inventors the exclusive rights to their respective writings and discoveries, . . ." I now quote from Title 42, Section 2182 of the Atomic Energy Act, which says: "Any invention or discovery useful in the production or utilization of special nuclear material or atomic energy, made or conceived under any contract, subcontract, arrangement or other relationship with the Commission, regardless of whether the contract or arrangement involved the expenditure of funds by the Commission, shall be deemed to have been made or conceived by the Commission."

Now, let me quote from Section 305 of Public Law 85-568, the National Aeronautics and Space Act of 1958, which says: "Whenever any invention is made in the performance of any work under contract of the Administration and the Administrator determines . . . and here I will paraphrase the language which refers to any person whether he is employed or not on the contract, and does or does not perform the work during working hours and does or does not use Government materials or information, etc. . . . such invention shall be the exclusive property of the United States and if such invention is patentable a patent therefore shall be issued to the United States upon application by the Administrator, unless the Administrator waives all or any part of the rights of the United States to such invention".

These three statements comprise the law of the land and I, for one, can find no shred of harmony among them. I submit that these two acts of the Congress most decisively and drastically violate the intent of the Founding Fathers.

What does this mean in practical terms? It means that should a salesman call on the purchasing department of a government prime contractor and leave drawings, specifications and samples of his product for consideration—and thousands of them are doing this every day—the United States Government at that precise point has full legal authority to order that product into production, by any plant in the country, using those drawings and specifications; it means that the prime contractor can duplicate the drawings and specifications and circulate them for bids for its own procurement in behalf of the government and can incorporate the product into its own proposals to the government. Obviously, in this space of seconds, the 169 year history of the nation's patent laws and the provisions of the Constitution of the United States are ground into shreds and dissolved into nothing.

Now, this is not a wild-eyed supposition. I asked the purchasing agent of one of the government's major missile manufacturers if my interpretation, as specifically stated above, was correct and his answer was: "Yes". I then went to Washington and asked this precise question of a defense agency official and his answer, likewise, was: "Yes". I then relayed this experience to a Congressman who had served on the Committee which wrote the Space Act and his reaction was stunned surprise.

I submit that the patent expert is not the legal counsel glibly versed in the verbiage of the law, nor is it the defense agency official fighting an energetic rear-guard action against this Constitutional right of the citizen. The real patent expert in America is the small business man who has lived with his patents, suffered their infringements by competitors, their compromise by the Government and sat helpless while the Congress, mesmerized by the dramatic presentations of the defense and space agencies, whittled away with enthusiasm at a right granted by the Founders of our nation.

Statham Instruments, Inc. is a microcosm of this tragic erosion of a Constitutional liberty, for it typifies the young man's perennial dream—shared by us all—of inventing something, getting it patented, and them making a million

dollars. This literally happened to Mr. Louis D. Statham, who now heads a company employing 800 workers producing about $10 million a year in sales of his patented product, in this case an unbonded strain gage transducer. His original patent has now grown into a portfolio of nearly 50 patents granted or pending and they represent the major asset of the enterprise. Impair the safeguards of these patent grants and you make serious inroads into his sales and profits, force the licensing authority to the government, or demand that all future creative development of the company become the property of the Government and you literally destroy this company and its contribution to science and our economy. And this company is only one of the 6,000 enterprises producing proprietary products for the nation's defense and space effort.

As citizens and taxpayers we most heartily endorse the policy of the Defense Department and the Government in general in attempting to obtain its equipment at the lowest reasonable price; but literally forcing such prices to low levels by flagrant disavowal of proprietary rights through usurpation of the patent grant is neither good business, equitable behavior nor within thes spirit and intent of the Constitution. It is not good business because it deliberately dissuades creative endeavor, thereby inherently restricting the flow of technological progress and impairing our runners in the scientific race with the Russians. It is not equitable because it places the creator of the product, who has a substantial investment in original research and development costs, in competition with simple job shops ready to translate the drawings into parts on a labor and materials cost basis with the usual 10 per cent profit allowance. This means simply that it places the patentee into competition with himself.

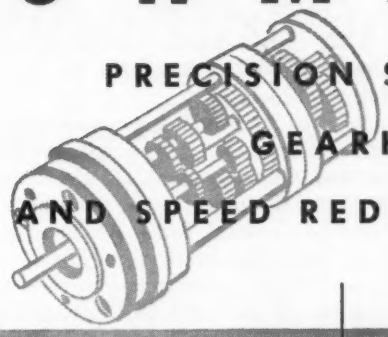
As a result, many manufacturers today simply and rigorously refuse to do business with our Government. They have not and do not intend ever to accept a government research and development contract and most are reluctant to accept purchase orders from government prime contractors which specify even minor changes in their standard product requiring engineering work and resulting special drawings. The resulting loss to our national defense effort in inventiveness and creativity is utterly incalculable.

The measurement industry is faced with the latest dilemma in this mounting paradox. It is now generally acknowledged that our missile and space programs have drawn abreast of our measurement capability. Entirely new inventions and discoveries are critically needed to enable us to measure accurately entirely new orders of magnitude in both capacity and resolution.

For example, the NASA, with the approval of the Congress, has sponsored contracts for the development of a rocket engine with a thrust of one million pounds. Assuredly all of us are enthused by this very great leap forward in our space capability, especially because high-thrust boosters is the one area in which we are most admittedly behind the Russians. Unfortunately, however, we have no means for measuring one million pounds of force to any useful standard accuracy. When the engine is delivered, the Government literally will not know whether it delivers one million pounds of thrust or not. Likewise there exists urgent Government demands for measurement capabilities in such areas as machining tolerances of five to twenty millionths of an inch, liquid pressures to accuracies within one-tenth of one per cent, temperatures above 5,000 degrees F to within a few degrees and vastly improved accuracies in the measurement of such familiar quantities as voltage, impedance and AC frequencies. Major General Donald Yates, Commander of the Air Force Missile Test Center at Cape Canaveral, Florida, characterizes this problem as a most serious bottleneck to our missile and space programs

BOWMAR

PRECISION SERVO GEARHEADS AND SPEED REDUCERS



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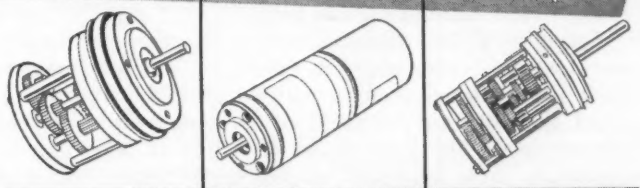

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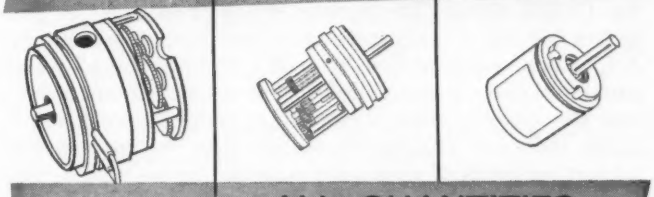
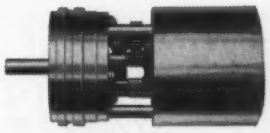


ALL QUANTITIES

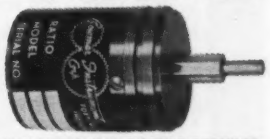
Bowmar designs and manufactures all types of precision geared components, assemblies and packages for all types of precision control systems. Dozens of semi-standard speed reducer and gearhead sizes are offered in most ratios; but these types may be altered, or entirely new types can be developed to fit new requirements. Typical of many Bowmar designs currently being manufactured — —

TWO SPEED GEARHEAD X-709. Unit shown has speed reductions of 2400:1 and 24000:1 for fast approach and slow zeroing. Unit is electrically actuated and is completely self contained. Typical of many Bowmar designs currently being manufactured.



PRECISION SERVO MOTOR GEARHEAD 750-GH (with housing). Standard ratios to 2000:1; Starting torque: .005 in.-oz.; Load torque: 5 in.-oz.; Backlash: 30 min. max.; Diameter: .750 in. Typical of many Bowmar designs currently being manufactured.

PRECISION MINIATURE SPEED REDUCER 1062. Standard ratios to 4000:1. Starting torque: .005 in.-oz.; Load torque: 25 in.-oz.; Backlash: 45 min. max.; Diameter: 1.062 in. Typical of many Bowmar designs currently being manufactured.



CONCENTRIC SHAFT SPEED REDUCER X-530. Single ended unit has optional internal slip clutch set to customer requirements. Most ratios available. Starting torque: .01 in.-oz.; Backlash: 30 min. max.; Diameter: 1.062 in. Typical of many Bowmar designs currently being manufactured.

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and says: "Certainly some break-throughs are necessary in the state-of-the-art if we are to satisfy the data acquisition needs for future vehicles".

Obviously there exist enormous economic opportunities for the measurement industry. But we know that under the law and current defense agencies administrative interpretations the "breakthroughs in the state-of-the-art" so urgently demanded by General Yates, which may cost the inventor anywhere from thousands to millions of dollars in development, will, upon acceptance, become the property of the government with full legal authority to award their quantity reduction and profit to one of his competitors, or, as flagrantly happens, to a company not even currently in the instrumentation field.

Faced with this dilemma, we must either deliberately sacrifice our brains and our talents on a horse race we know is fixed in advance, or with equal deliberation simply avoid the risk and withhold of our creativity from this critical need. The first course of action is becoming increasingly sheer economic stupidity; the latter course of action is unpatriotic to the edge of figurative treason.

The culprit in this impasse is clearly the Congress of the United States. The massive breakthrough in the protective barrier of the patent grant was the Atomic Energy Act, which was spawned in a day of frightening awe of atomic weapons compounded by the most rigorous secrecy ever shrouding a subject. Now I am certainly not going to argue that our citizens should be free to manufacture nuclear weapons of their own patented inventions in their backyard workshops, nor that the United States Government does not have an overriding interest in nuclear weapons developments wherever they might occur. But it is this unique Act, *created for one of the most highly specialized purposes in the history of the Congress, that is increasingly the model for equally assumptive patent clauses in other enabling legislation and executive and administrative orders.* The pattern now well developed in this area displays the perhaps innocent, but nevertheless, thoughtless zeal of the bureaucrat for garnering into government title virtually everything in sight.

The line between private property and public welfare is tenuous in the extreme and some of the law profession make a very comfortable living out of the vagaries of such a line. But none can doubt that it does exist and that it can be clearly identified—black and solid—in any specific instance. The juridical problem here is that in the practice of usurping for the Government all those things held overriding of private property, the Government is relentlessly drying up the fountain of such property. When the stream of technological creativity in the United States goes dry, we will be well on our way into the history books of prior civilizations. Yet I must warn you, with all the solemnity at my command, that this is the course we are now on—and we are picking up speed.

The responsible members of Congress must recognize the urgency of a formal reaffirmation of the Constitution's guarantee of the citizen's exclusive right for a limited time to the fruits of his inventions and discoveries, regardless of their nature. With such reaffirmation by an Act of Congress, the restrictive and presumptive clauses in defense agency authority will be forced into harmony with our Constitutional guarantee and the creative citizens re-enlisted enthusiastically for service on the national scientific frontier, the battleground on which the issue of our survival will be fought.

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WORTH FILING

Relay Definitions and Testing Procedures

Seventy page progress report by the National Association of Relay Manufacturers' Technical Committees covers dry circuits (low energy switching), measurement of electrical characteristics, contact life testing and environmental testing. The report presents suggested definitions and test procedures, discusses test equipment and precautions, outlines work yet to be done and solicits comments and suggestions on work accomplished to date.

Source: National Association of Relay Manufacturers
Stillwater, Oklahoma
For your copy: Circle No. 237 on Inquiry Card

WORTH FILING

Flight Controls

8 page bulletin contains detailed application information on self-adaptive flight control, all-transistor control amplifier, inertial guidance platform, gyros, accelerometers, high temperature pneumatic servo valve, hot gas servo, liquid metals, electrostatic gyro, plus automatic ground support test equipment.

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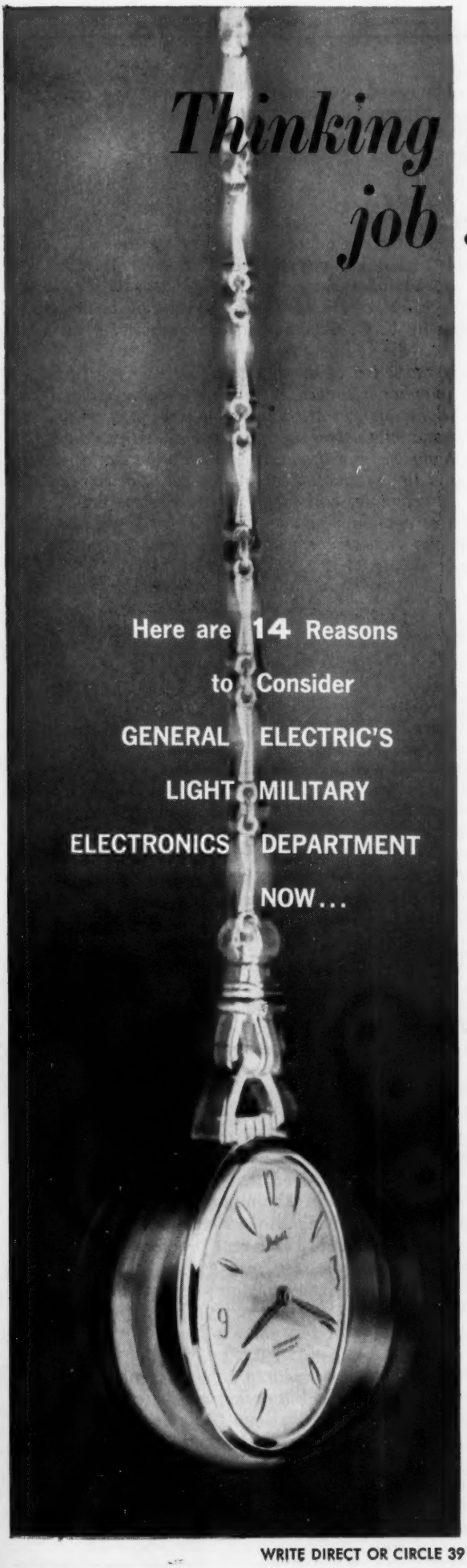

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THE TECHNIQUE OF ORIGINALITY

Originality, like inventing, is not a strange, mysterious power possessed by only a "gifted few". It is an everyday mental power that most persons possess in greater or less degree. For originality can be considered as the knack of detecting what we are taking for granted, questioning it, and re-evaluating by using the results of that questioning. Here are a few examples that illustrate this point and that may help you to develop this faculty.

Probably the most striking illustration of the technique of originality is in the solution to the problem of sending telephone messages over great distances. Soon after Bell invented the telephone, engineers found that the power in a telephone circuit fell off very rapidly as the length of the transmission line increased. Thus to transmit speech a considerable distance, an enormous amount of power had to be supplied at the input end of the telephone circuit to operate a receiver at a far distant point. Because this high power requirement was impractical, engineers turned to the next most obvious idea—boosting the power of the transmitter every few miles, thereby providing adequate strength of signal at the distant receiver to reproduce the transmitted sound without using excessive

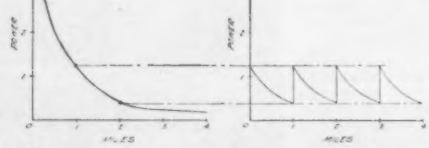

Fig. 1 Rapid fall-off of power with distance of telephone transmission requires excessive power input (Curve A) or much sma'ler inputs at frequent intervals (Curve B).

amounts of power. Fig. 1 presents these two methods graphically.

At the time this problem arose (about 1900), engineers were imbued with the success of the telegraph relay as a power booster for signals sent over electrical circuits. In the telegraph relay a feeble current energizes an electromagnet which in turn closes the switch of a second cir-

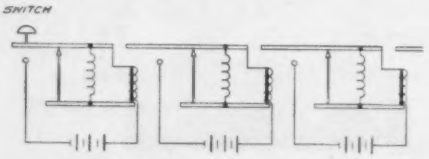

Fig. 2. Periodic boosting of telegraph signal by relays to permit long-dis'ance transmission.

cuit in which a far greater current flows (Fig. 2). Essentially, the procedure amplifies the signal by converting electrical energy into mechanical then back to electrical. Hence almost all inventors tackling the problem of boosting the telephone signal's power automatically took for granted that the same relay principle had to be followed —that is, one had to convert repeatedly from electrical to mechanical, then back again just as the telegraph relay did. So a swarm of inventions were conceived in which the telephone signal is boosted by a chain of rather short circuits in which a microphone picks up the weak sound from the preceding circuit and a receiver transmits the sound to the following circuit.

On Page 501 of **History of the Telephone in the United Kingdom** by F. G. C. Baldwin, one authority says:

> *"The production of an appliance for relaying (repeating) telephonic speech in much the same manner as telegraphic signals are repeated has been a dream of telephone engineers ever since the earliest days of telephony. . . . For the most part attention was directed towards the production of a repeater, electromechanical in principle, and many of the devices have consisted essentially of an arrangement of some form of telephone transmitter and sensitive receiver in combination."*

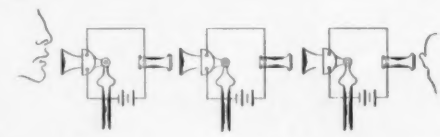

Fig. 3. Boosting the power of the telephone signal by receiver-transmitter repeater chain.

Fig. 3 shows the nature of this solution. Further observations and particular devices of this type may be found in **Conqueror of Space, Life of Lee DeForest** by G. Carneal and in **History of Radio Telegraphy and Telephony** by G. G. Blake.

A few inventors, however, did not take the telegraph relay concept of amplification for granted. Instead they recognized the concept, questioned it, and found that repeated direct amplification of the telephone current itself (at frequent points along the circuit), without converting it back and forth into speech, was the principle called for in boosting the power of telephone signals and proceeded to invent something to do that job.

Two different inventors arrived at the same solution for this problem—the three element (triode) vacuum tube. One, an Austrian, Von Liebig, arrived at it indirectly by inventing a three-element grid-controlled vacuum tube, contrived primarily to control the intensity of the beam of an X-ray tube. However, he had the telephone relay problem in mind and recognized that he had the answer to it as revealed in his patent. The other was an American, Lee DeForest, who, in 1907, also arrived at the solution indirectly when he solved a different problem—the detection of radio waves. But he also realized how well his invention solved the telephone relay problem when he hooked up a few of them in cascade and parlayed the small amplifying effect of each tube into a huge over-all amplifying action.

In the three-element vacuum tube a considerable electron current flows across the evacuated space inside a glass bulb from a hot filament that emits the electrons to a positively charged plate that collects them. A wire, mesh or grid, inserted between them and subjected to slight variations in voltage varies the strength of the "space" current. Fig. 4 illustrates the principle. Consequently, feeble telephone signal voltages at the end of a long line, when

applied to the grid of a vacuum tube, produce corresponding fluctuations in the much larger space current, delivering direct amplification of telephone signal currents (Fig. 5).

Thus we see that those inventors who took the telegraph relay principle for granted, in trying to solve the telephone signal boosting problem, failed. Others either directly

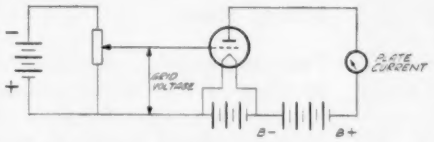

Fig. 4. Grid control of space current in 3-element vacuum tube.

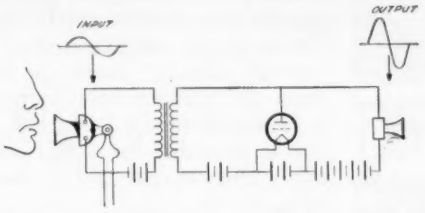

Fig. 5. Direct amplification of telephone currents by 3-element vacuum tube.

or indirectly questioned the conversion of electrical to mechanical and back to electrical, found it did not meet the challenge, and arrived at the solution to the problem of direct amplification of telephone currents. The fact that some of them came to this realization by an indirect route does not alter the basic picture: To provide an original solution to an invention problem, you must detect what you take for granted, question it, and devise a solution in accordance with the results of that questioning. This, in essence, is one prime factor in the technique of originality.

The next column discusses the manner in which you can attack design or invention problems from different viewpoints—a procedure I label the "Progressive, Reciprocal, Revision Process".

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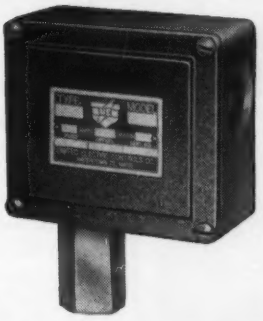

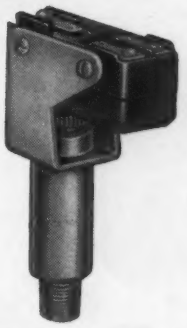

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On-Off Switch Differential	Fixed and uniform throughout specified range is standard
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Capable of rapid adjustment, even while the instrument is operating, the function generator is composed of two separate units, a function adjusting assembly, housed in a steel case approximately 3 x 6 x 8 inches, and a cable-connected interpolating Vernistat, which is available in synchro size 11 or 18 housing or in a 3½ inch housing with a dial indicating shaft position.

The function adjusting asembly is basically a 34 pole, 101 position printed circuit switch. An integral voltage divider (tapped autotransformer) provides voltages to the 101 switch positions in 1% increments. The poles are easily operated sliding contacts which select 34 voltage levels within ± ½% of any desired value. The interpolating Vernistat accepts the selected voltages via the connecting cable and, as its shaft is rotated, performs linear interpolation between the voltages appearing at adjacent sliding contacts. Perkin-Elmer Corporation, Norwalk, Conn.

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Automatic Control Timer

D-C reset timer for automatic control of machine process functions will control loads within variable timed intervals with a repeat accuracy of ¼ of 1%. It will reset full scale length in less than 1/10th of a second, or stop on power failure or power interruption. Seven basic circuit arrangements provide an infinite number of combinations and exclusive metal to neoprene impingement clutch allows millions of operations without clutch wear or slippage. Also featured are self-cleaning heavy duty silver contacts. Automatic Timing & Controls, Inc., King of Prussia, Pa.

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Timing Relay

Two single-pole, double-throw snap switches of a pneumatic timing relay operate two normally open and two normally closed timed contacts. Each switch can be separately adjusted to provide a definite timing sequence. Up to two instantaneous single-pole, double-throw interlocks can be furnished. Timing range is adjustable from 0.2 seconds to 3 minutes, with a repeat accuracy of ±10%. The relay is available for either a-c or d-c operation. Square D Co., Milwaukee, Wisc.

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Electrical Two-Speed Synchro

Accurate shaft position data transmission is a continuing problem in determining such factors as gyro position or antenna azimuth. Up to the present time two systems, each composed of a synchro transmitter and control transformer, were used. One system was driven through a gear train at a multiple of the speed of the other and theoretically, accuracy was multiplied by the gear ratio. In practice, however, accurate indication was limited by gear tolerances and backlash.

To answer this problem, a two-speed-synchro produces two electrical outputs from a single-shaft unit, thereby eliminating the inaccuracies connected with gearing.

The synchro stator contains two separate windings. One set produces the normal signal pattern of one cycle of output voltage, while the other produces 11 cycles, for each rotation of the synchro shaft. The unit thus offers the same increase in accuracy as an eleven-to-one gear ratio without any of the problems inherent in a gear train. The course or fine output can be selected through a switching system located outside the unit. Extensive tests have shown that system error can be held to 1.4 minutes or less. Excellent static accuracy and a 350:1 signal-to-null ratio will allow engineers to design systems to the test bench specifications of the unit. A unique winding design eliminates errors due to clamping and uneven expansion or contraction of the magnetic structure. Bendix Avaition Corp., Teterboro, N. J.

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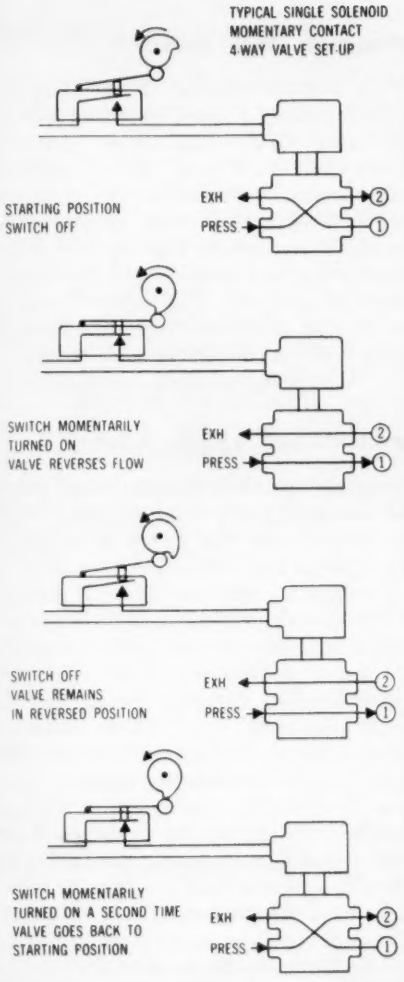

Momentary Contact Air Valves

By means of a cam and switch arrangement, Barksdale Valves of Los Angeles, California has designed a single and dual solenoid valve in which current is applied only for the instant it takes the valve to change position. It remains in that position with the power off.

In the single solenoid 2-position 4-way valve, when solenoid is actuated by electric impulse, the solenoid plunger moves down actuating the pilot valve which in turn, operates the main valve. The momentary contact device then "latches" the pilot valve in this position, even after power is cut-off. When an electric impulse once more energizes the solenoid, the solenoid plunger "unlatches" the contact device and allows the pilot valve and main valve members to revert to the original normal position. The solenoid is de-energized and the valve remains in this position until the next actuation.

Dual Solenoid Units, for use in automated systems, prevent the valve from getting out of phase. In this unit, solenoid #1 is actuated and the pilot valve is latched as described above. But additional electric impulses to solenoid #1 will not unlatch the pilot valve. Only by actuating solenoid #2 does the valve revert to its normal position.

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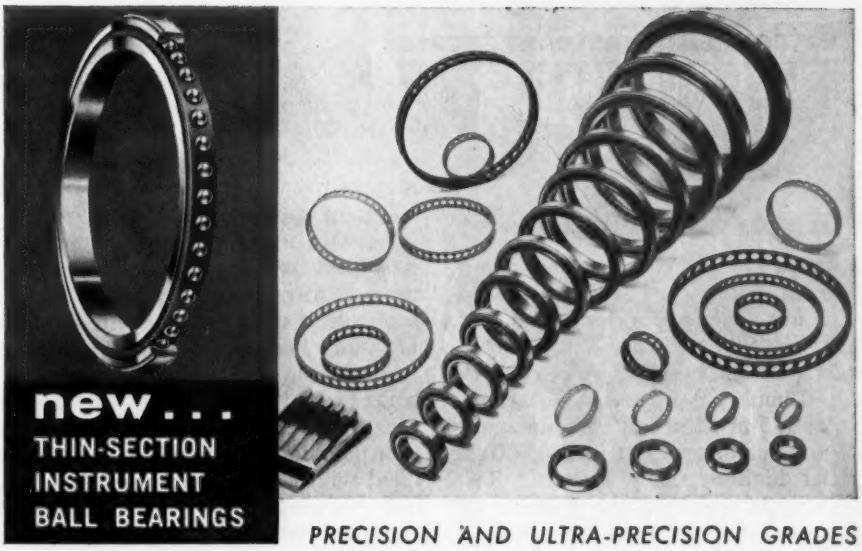

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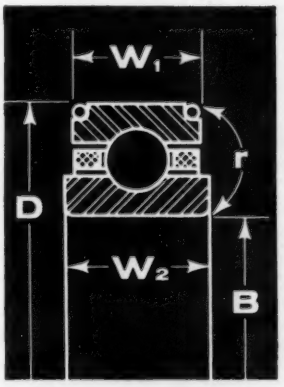

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TCR 12-19	.7500	1.1875	.250	.281	18	1/8	.037	280	490
TCR 14-21	.8750	1.3125	.250	.281	20	1/8	.042	310	540
TCR 17-24	1.0625	1.5000	.250	.281	24	1/8	.05	360	650
TCR 21-28	1.3125	1.7500	.250	.281	28	1/8	.06	370	760
TCR 25-32	1.5625	2.0000	.250	.281	34	1/8	.07	390	925
TCR 29-36	1.8125	2.2500	.250	.281	38	1/8	.08	410	1030
TCR 33-42	2.0625	2.6250	.250	.281	44	1/8	.12	435	1200
TCR 37-46	2.3125	2.8750	.250	.281	48	1/8	.13	450	1300
TCR 41-52	2.5625	3.2500	.312	.375	36	3/16	.22	835	2200
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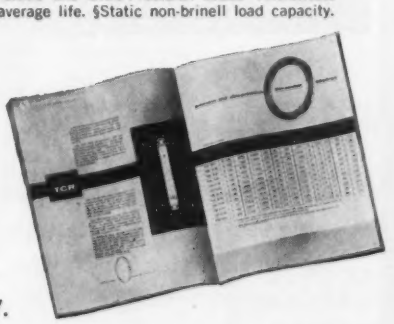

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Vertical Sensor

A sensitive electrical plumb-bob is the newest instrument used to check that a missile is exactly erect on its launching pad. Formally known as the Vertical Sensor, the unit can determine true vertical within three minutes of arc. The vertical sensor consists of an iron pendulum suspended in a 5″ tube filled with a damping fluid. Miniature coils spaced 90° apart at the bottom of the tube, form magnetic pickups which detect any deviation of the pendulum from center position. Where excitation is applied (5 volts, 400 cycles), the pickups produce an output which increases linearly as the unit tilts from the vertical. The signals are fed to output terminals on the side of the tube, and can be measured with a VTVM. When the tube is exactly upright, within ± three minutes, the unit is at electrical null. Cross coupling between the two pickups is held to a minimum. Total unit weighs only 2½ ounces. Eclipse Pioneer Div., Bendix Aviation Corp., Teterboro, New Jersey.

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Circle No. 213 on Inquiry Card

Miniature D-C Motor

DC motors are 1⅜ inches in diameter, have continuous duty ratings to 1/100 HP, and can be wound for series, split-series, shunt or universal operation. Length of the motor is determined by the stack length chosen. A particular feature of the unit is that torques to 6 oz. in. can be obtained for intermittent duty. These motors lend themselves to integral brakes which are capable of full load speed stops in 2.9 revolutions. Brake adds 1⅛ inch to overall motor length. Various types of governors may be used, and integral planetary gear speed reducers are available in hundreds of ratios. Motors can use 6 to 75 v.d.c., providing output speeds in the range 6,000 to 13,000 rpm. Globe Industries, Inc., Dayton, Ohio.

Circle No. 230 on Inquiry Card

Motion Transducers

A line of brushless, motion (linear and rotary) transducers represent a new concept in variable-reluctance transformers, having very high sensitivity at low impedance levels and excellent linearity over a wide input range. Formally known as Transipot, these units have infinite resolution, high efficiency, and inherent reliability using modular construction with a standard servo mounting. All models are rated for operation to 125C. Typical specifications are: input range, 20, 50, or 100 mils; sensitivity, 1 volt rms/mil; input, 26 volt ac—400 cps; output impedance, 1000 ohms; independent linearity, 0.5%; null (timed), 0.1%; and useable frequency range of 300-3000 cps. Arnoux Corporation, L. A., Cal.

Circle No. 219 on Inquiry Card

New Size 18 Servomotor

115 volt, 60-cycle size 18 servomotor is engineered to provide the high torque and instantaneous acceleration required for rapid, precise response to minimum control signals. Weighing in at 15 oz., it has completely encapsulated windings and a housing of stainless steel, requires a power input of 9 watts/phase with 0.64 power factor, and can be wound for any standard carrier voltage supply. Performance characteristics include no-load speed of 3200 rpm, torque and acceleration at stall of 4 ounce-inches and 70,000 rad/sec^2 respectively, and continuous operation at stall to unit temperatures of 200C. Helipot Division of Beckman Instruments, Inc., Fullerton, Cal.

Circle No. 157 on Inquiry Card.

Linear Actuator

A linear actuator contains three major sub-assemblies: motor and clutch brake assembly with integral thermal protector; junction box with electrical components; and gearbox and jackscrew. These sub-assemblies can be removed separately for repair or replacement without completely disassembling the entire actuator. Other design features are: electrical load sensing mechanism that permits the actuator to sense, shut off and hold a predetermined load of 500 to 800 lbs; electro-magnetic clutch brake that provides irreversability within the design load range to 1000 lbs. in the current off condition; normal load 300 lbs. at 3.5" per second travel rate; 31" stroke, 28 volt d-c operation; close tolerance reduction gearing for long life and a radio noise filter to MIL-I-6181B. Hoover Electric Co., Los Angeles, Cal.

Circle No. 142 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT

Floated Rate Integrating Gyros

Specifically designed for missile applications, these Kearfott miniature gyros operate efficiently at unlimited altitudes. Their outstanding accuracy and performance make them superior to any comparably-sized units on the market. Hermetically sealed within a thermal jacket, these gyros are ruggedly designed and completely adaptable to production methods. Performance characteristics that are even more precise can be provided within the same dimensions.

TYPICAL CHARACTERISTICS

Mass Unbalance:
Along Input Axis: 1.0°/ hr maximum untrimmed
Standard Deviation (short term):
Azimuth Position: 0.05°/hr
Vertical Position: 0.03°/hr
Drift Rate Due to Anisoelasticity
Steady Acceleration:
.015°/hr./g^2 maximum
Vibratory Acceleration:
.008°/hr./g^2 maximum
Damping:
Ratio of input angle to output angle is 0.2
Characteristic Time:
.0035 seconds or less
Weight: 0.7 lbs.
Warm-Up Time:
10 minutes from −60°F
Life: 1000 hours minimum

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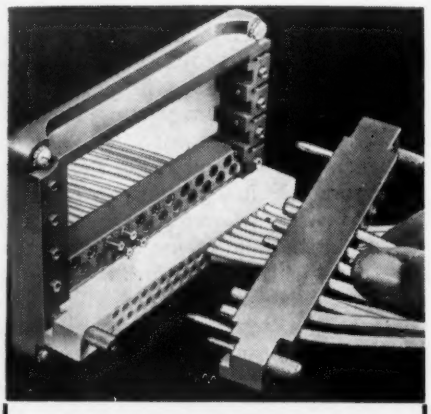
ELECTROMECHANICAL COMPONENTS



Versatile Connector For Miniature Coax

A highly versatile compression-type Hyfen gang connector for miniature coaxial cable has been introduced by the Omaton division of Burndy Corporation, Norwalk, Conn. The connector's pin and socket contacts are crimped to both inner and outer conductors, connecting RG195U cable and #24 shielded miniature coax cable, the inner conductor of which has seven #32 strands. Connectors for other sizes of coax cable are under development. Connector frames will accommodate three, five or eight inserts, snapped in from either front or back. Inserts for coax cable accommodate up to 21 pins or sockets. A plug or receptacle insert may hold either male or female contacts, or they may be intermixed. Coax cable inserts and standard wire inserts may be mounted in the same frame. Contacts can be crimped to cable ends either after the harness is in place, or on a high-speed production basis, away from the equipment to be wired. Engaging and disengaging forces of low magnitude make it easy to insert, remove, and replace contacts and insert individually, for flexibility in circuit changes.

Circle No. 77 on Inquiry Card

Peak Reading Digital Voltmeter

A fully-transistorized digital voltmeter measures and displays the peak amplitude in a single-event, positive-going pulse in an in-line in-plane digital form. Both decimal and binary-coded decimal electrical outputs are provided and duration of pulses can vary from 0.1 milliseconds to 2.0 milliseconds. The adjustment-free unit contains a pulse detector with the voltmeter. Solid state plug-in circuitry is employed throughout. Epsco, Inc., Cambridge, Mass.

Circle No. 191 on Inquiry Card.

New Electronic Components For Electromechanical Systems

Multigun Storage Tube

A multigun, all glass, direct view storage tube with electrostatic focus and deflection has a 10-inch diameter face and features "simulscan" writing so that one gun, for example, can write a PPI scan while the other uses a conventional TV raster scan. These tubes can be made with as many as fifteen different guns for the purpose of categorizing and pinpointing specific targets and information. Additional features that add new dimensions and usefulness to storage tubes are high resolution, full half-tone range, high brightness, versatility of electrostatic focus and deflection and flexible storage time, which can be adjusted to show current information only or current and past information only. DuMont Labs, Clifton, N.J.

Circle No. 134 on Inquiry Card

Driver Transistors

A series of three new medium power audio transistors designed as a power transistor driver, are particularly useful in applications where versatility and low cost are principal design considerations. Contained in the JEDEC TO-9 package, the transistor is capable of dissipating 300 mw at 75C. High current gain with linear characteristics results in low distortion output. These transistors feature low saturation resistance with typical values of one ohm at 100 ma dc, 15, 40, and 60 volts and a maximum current rating of 300 ma dc. Welded construction and a vacuum-tight seal insure long life and stable operation. Semiconductor Prods., Bendix Aviation Corp., Long Branch, N.J.

Circle No. 136 on Inquiry Card

Universal Amplifier

One basic amplifier with interchangeable tubes and other plug-in components handles inputs of a-c or d-c signals with either isolated low impedance or non-isolated low, medium or high resistance with gains from 0 to 5,000,000. 6 ¾" x 4 ¼" x 6" in size and weighing only 4 lbs. 12 oz., this new amplifier operates from standard a-c power supplies—115 volts ±20%, 50 or 60 cycle ± 3 cps. The Hays Corp., Michigan City, Ind.

Circle No. 144 on Inquiry Card

Thermocouples for 2000F Ambients

Insulated, metal sheathed thermocouple wires have been designed to withstand ambient temperatures of 2000F plus for use where high temperatures must be accurately measured and where thermocouple leads must pass through zones of extreme heat. Insulation is specially selected crystalline magnesium oxide compacted to maximum density inside the sheath. Inconel sheaths are completely impervious to moisture, oils, petroleums, ozone and solvents, and are immune to age deterioration. Twelve standard constructions, with wire gage sizes from 15 to 28, can be furnished from stock. Revere Corp., Wallingford, Conn.

Circle No. 211 on Inquiry Card

AC Voltmeter

A battery-operated, general purpose ac voltmeter with a frequency range of 1 cps to 1 mc is transistorized and compact weighing less than 5 pounds. Measuring ac voltages from 1 millivolt to 300 volts full scale, with an accuracy of ±3% 5cps to 500 KC and ±5% 1 to 5 cps and 500 KC to 1 MC, the instrument has 12 voltage ranges and reads from −72 to +52 db. Battery has 400 hours of life and its voltage may be checked easily at any time by a front panel switch, thereby assuring reliable measurements. The voltmeter is completely isolated from power line or ground interference: price: $250.00. Hewlett-Packard Co., Palo Alto, Cal.

Circle No. 159 on Inquiry Card.

Tiny Indicator Lamp

Microminiature incandescent indicator lamp which operates directly from the output of a transistor without amplification draws less than 50 milliamperes at less than 6 volts. It is housed in a vial .110 in. long and .050 in. in diameter, with two platinum leads extending from one end. Precision built for long lasting, trouble-free operation it is applicable in computers and a wide variety of military electronic devices where size and low current requirement are important. Minitron Components Corp., Paterson, N.J.

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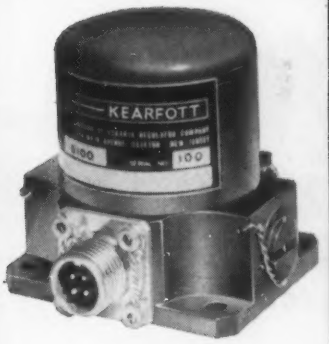
BASIC BUILDING BLOCKS FROM KEARFOTT



Electrohydraulic . . Servo Valve

Kearfott's unique approach to electrohydraulic feedback amplification design has resulted in a high-performance miniature servo valve with just two moving parts. Ideally suited to missile, aircraft and industrial applications, these anti-clogging, 2-stage, 4-way selector valves provide high frequency response and proved reliability even with highly contaminated fluids and under conditions of extreme temperature.

TYPICAL CHARACTERISTICS

Quiescent Flow ..... 0.15 gpm
Hysteresis ... 3% of rated current
Frequency Response 3 db @ 100 cps
Supply pressure....500 to 3000 psi
Temperature-Fluid & Ambient −65° F to +275° F
Flow Rate Range ..... .3 to 10 gpm
Weight ..... 10.5 ounces

Write for complete data.

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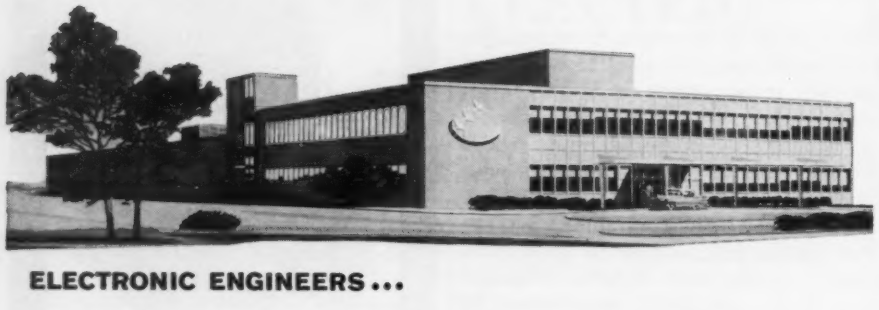
Circle No. 44 on Inquiry Card

Scheduled to open about the first of the year, Republic's new Research & Development Center at Farmingdale, Long Island, New York, will comprise seven different laboratory facilities. Included are an Electronic Development Laboratory and a Guidance and Control Systems Laboratory. These modern facilities will contain the most up-to-date equipment obtainable for the research, development and test of advanced astrionic and avionic systems, equipments and components.



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ELECTRONIC COMPONENTS

Micro Micro-Diode

So small it looks to the naked eye like a flyspeck on a wire, a "micro-micro" diode can withstand space shocks of 20,000 times gravity. This speck-like vacuum tube replacement represents a significant step toward hand-sized computers and pocket-sized space instrumentation systems.

The new device weighs 14.09 mg and is unique in that it represents an unusual chemical bonding of the molecules of the silicon crystal with surface elements that serve as a protective coating. The new molecular bonding is said to be one of the secrets of the size reduction. Pacific Semiconductors, Inc., L. A., Cal.

Circle No. 209 on Inquiry Card

Zener Voltage Regulators

Gold crown silicon zener voltage regulators which extend the control range to 100 volts are available in power ratings up to ¾ watt, 1 watt, 3.5 watts and 10 watts. Hermetically sealed, these devices insure high reliability for many applications in instruments, computers and industrial equipment. Int'l Tel & Tel Corp., Clifton, N.J.

Circle No. 135 on Inquiry Card

Multiple Preset Counter

A compact solid-state multiple preset counter will withstand severe environments: shock, vibration, explosive atmospheres, liquid splash, oil mist, moisture, dust, dirt, etc. The instrument is housed in a reinforced steel enclosure which is sealed against front and rear aluminum castings drawn together by internal and/or external tie bolts. Individual, pluggable counting and control modules are used for rapid application adaptability and easy maintenance. Through the use of optional mounting brackets and connector location, the unit can be mounted directly on the controlled machine for easy operator access to control settings. Reset may be local or remote. Electrical and physical specifications are: 6 million counts per minute maximum; 50 millivolts sensitivity; standard preset count range is 1 to 9,999 (5 to 8 digit units also available); pulse, or relay output with latch or variable relay hold time; dual preset available for control at preset counts A and/or B, or alternate control; power required is 18v dc at 0.2 amp; standard power supplies for 24v, 115v, 230v, 50 to 400 cps line frequency; size is 3½" high x 9½" wide x 13" deep; weight is less than 10 pounds. Erie-Pacific, Div. of Erie Resistor Corp., Erie, Pa.

Circle No. 222 on Inquiry Card

New Mechanical Components For Electromechanical Systems

Clock Counter

A clock type counter provides 24-hour indications in minutes and hours for elapsed time readout applications. Quarter-inch high white characters on black drums giving easily read information, allows for large numeral readout in a small frame package. The "minutes" drum is graduated in increments of 2/10 of a minute for fine readings. Operable at speeds to 300 rpm for zeroing purposes, the counter's normal speed is 1/10 rpm at the input shaft. One revolution of the shaft provides 10 minutes of indication. The units designed in various types and configurations can be used in temperature ranges from −30°C, where input torque is .75 in-oz., to 71°C. Bowmar Instrument Corp., Fort Wayne, Indiana.

Circle No. 189 on Inquiry Card.

Coaxial Cable Disconnects

Coaxial and shielded cable disconnects have been expanded to fit a wider range of cable sizes. Interchangeable contacts permit a greater variation of inner conductor diameters in each cable size—either solid or stranded. Application technique requires one crimp for complete assembly. AMP, Inc., Harrisburg, Pa.

Circle No. 143 on Inquiry Card

Dual Bank Counters

High speed dual bank counters with shutters arranged to give plus or minus, or north and south readings, are built with nylon wheels and pinions to reduce torque and give lower moment of inertia, higher speed and longer life.

At zero position, both of the shutters are open. When the counter is driven forward, a shutter covers the minus bank of figures and the plus bank remains visible, showing the adding as it progresses. The minus bank, though not visible, is subtracting at the same time. One revolution of the shaft is equal to one revolution of the first wheel, or ten counts to one revolution of the shaft. The unit can operate over a range of from 55C to 75C. Durant Manufacturing Company, Milwaukee, Wisconsin.

Circle No. 208 on Inquiry Card.

Precision Rotating Components

Standard gear heads, speed reducers and speed increasers, in a wide variety of ratios in sizes 8, 10, 11, 15 and 18 are designed for extreme reliability and are capable of transmitting higher torque in a comparatively shorter over all length. All units conform to applicable military specifications; operate from minus 55 to plus 150 degrees centigrade; have maximum backlash at output shaft of thirty minutes in any ratio; use either sleeve or ABEC 7 ball bearings; are available with preset mechanical slip clutch for overload protection. Kinetic Instrument Corp., Brooklyn, New York.

Circle No. 207 on Inquiry Card.

Shock and Vibration Isolators

Shock and vibration isolators, for use at temperatures up to 500F, consist of two load carrying springs, mounted in opposed positions, with a built-in damper assembly to restrict resonant buildup. The diameters of the springs, the wire diameter, the assembled length, the number of turns of wire and the helix angle of the spring are controlled to give desired spring rates in directions parallel to and perpendicular to the axis of the isolator. Units can restrict maximum resonant buildups in the low-frequency range to well below 3½ to 1 in any direction of vibration without sacrificing high-frequency isolation efficiency. Equal spring rates in all directions are available. MB Electronics, New Haven, Conn.

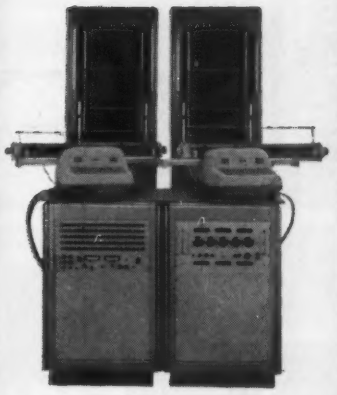
Circle No. 241 on Inquiry Card

Flip-Loc Fastener

A quick-action line is completely self-contained with no loose parts to go astray. Called the Flip-Loc Fastener, the clamp has 3 exclusive design features; a rugged hinge built into the parent metal itself, which allows the clamp to be opened and closed without any binding or distorting; an exclusive quick disconnect nut that can be disengaged with just 1¼ turn of a screwdriver on its integrated bolthead; clamp can be opened and closed without removal from its fixed mount. Other features are self-alignment, temporary finger closure, all captive parts, high strength, distortion-free design. TA Mfg. Corp., L. A., Cal.

Cicle No. 232 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT



Data Logging

Kearfott's broad line of test equipment includes the Scanalog 200-Scan Alarm Logging System which monitors, logs and performs an alarm function of up to 200 separate temperature, pressure, liquid level or flow transmitters. This precise data handling system is equipped with manual controls for scanning rates, automatic or manual logging, data input relating to operator, time, day, run number and type of run. 200 numbered lights correspond to specific points being maintained and provide a visual "off normal" display for operator's warning. System can be expanded to 1024 points capacity and 2000 points per second scanning rate.

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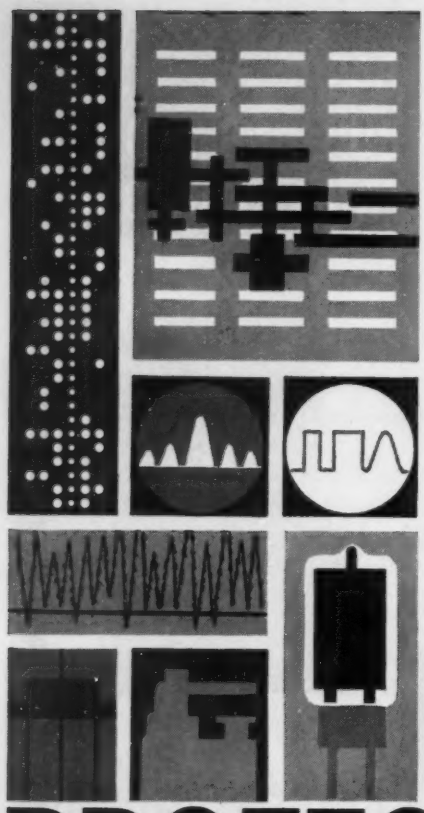

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MECHANICAL COMPONENTS

Sealed Torque Transmitter

Hermetically sealed torque transmitter imparts rotary motion through a positive metal-to-metal seal by means of a flexible metal bellows. Apparatus requiring adjustment or control without disturbing hermetic sealing, may be regulated from outside a sealed area by using the new transmitter. Weighing only 0.87 ounce, the transmitter is 2½ inches long and ¾ inch in diameter. It has a minimum life of 100,000 revolutions and an operating temperature range of 57 to 125C. Input and output shafts are ball-bearing mounted to minimize friction. No gaskets or sliding seals are used. Hoffman Electronics Corp., Los Angeles, Cal.

Circle No. 255 on Inquiry Card

UHF Socket

Completely assembled and ready to solder into chassis, a new UHF socket features very low capacitance from cathode to ground and from anode to ground, and will accept tubes in the 2C39 series. Rexolite 1422 insulators are used for their extremely low loss and low dielectric constant characteristics at VHF and UHF. Heat treated, heavily silver plated, beryllium copper, finger springs make multiple peripheral contact with the tube elements. The socket construction prevents undue strain on the tube since the tube is not clamped in the socket, but held captive by two lugs at the anode end. Jettron Products, Inc., Hanover, N. J.

Circle No. 214 on Inquiry Card

Self-Locking Aluminum Nuts

A new economical self-locking aluminum locknut, called the "Tru-Lok" incorporates a high strength, spring-temper stainless steel wire form in an aluminum body—a combination which invests the "Tru-Lok" with properties to meet all the performance requirements of MIL-C-25027 for 550F operation as well as 250F. Specific configurations shaped into the middle winding of the coil produce accurately controlled pressure, exerted uniformly and radially, for unvarying torque and locking friction that assures vibration-proof, constant position. Among the significant properties are: extensive reusability; negligible wear, no galling, seizing, or deformation of mating threads; high strength-to-weight—resulting from the high strength coil and the light weight body. Waltham Precision Instrument Co., Waltham, Mass.

Circle No. 258 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT

Analog-to-Digital Converters

Kearfott's rugged shaft position-to-digital converters are resistant to high shock and vibration and high and low temperature environments. Ideally suited for missile applications, these converters are available for many uses, including latitude, longitude, azimuth or conventional angular shaft displacement conversion and decimal count conversion. Exclusive drum design provides large conversion capacity in smallest size. Combination counter converter assemblies for both visual and electrical readout also available.

TYPICAL CHARACTERISTICS

Kearfott Unit No.	P1241-11A
Code	Cyclic Binary
Range	0-32,768 (2^{15})
Bits per Revolution	16
Revolutions for Total Range	2,048
Volts D.C.	10.5
Current (ma.)	20
Inertia (gm. cm.^{2})	20
Unit Diameter (in.)	1 1/16
Unit Length (in.)	3
Life	10^6 Revolutions or 10^3 hours
Static Torque (in.-oz.)	2 (break) 1 (running)
Weight (oz.)	5
Maximum Speed (RPM)	600

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BASIC BUILDING BLOCKS FROM KEARFOTT

20 Second Synchro

This synchro, just one of a broad line offered by Kearfott, provides the extreme accuracy required in today's data transmission systems. Kearfott synchro resolvers enable system designers to achieve unusual accuracy without the need for 2-speed servos and elaborate electronics. By proper impedance matches, up to 64 resolver control transformers can also operate from one resolver transmitter.

TYPICAL CHARACTERISTICS — SIZE 25

	Transmitter	Control Transformer
Type Resolver Part Number	Z5161-001	Z5151-003
Excit. Volts (Max.)	115	90
Frequency (cps)	400	400
Primary Imped.	400/80°	8500/80°
Secondary Imped.	260/80°	14000/80°
Transform. Ratio	.7826	1.278
Max. Error fr. E.Z.	20 seconds	20 seconds
Primary	Rotor	Stator

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

Integrating Tachometers

Kearfott integrating tachometers, special types of rate generators, are almost invariably provided integrally coupled to a motor. They feature tachometer generators of high output-to-null ratio and are temperature stabilized or compensated for highest accuracy integration and rate computation. Linearity of these compact, lightweight tachometers ranges as low as .01% and is usually better than ± .1%.

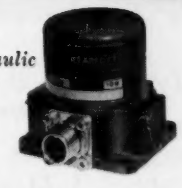
TYPICAL CHARACTERISTICS

	Size 11 (R860)
Excitation Voltage (400 cps)	115
Volts at 0 rpm (RMS)	.020
Volts at 1000 rpm (RMS)	2.75
Phase shift at 3600 rpm	0°
Linearity at 0-3600 rpm	.07
Operating Temperature Range	−54° +125°

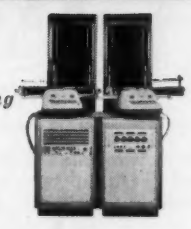
Write for complete data.

Miniature Floated Gyro

Electrohydraulic Servo Valve



Scanalog 200-Scan Alarm Logging System



Engineers: Kearfott offers challenging opportunities in advanced component and system development.

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ON CONVERTERS
CIRCLE 47 ON INQUIRY CARD

ON SYNCHROS
CIRCLE 48 ON INQUIRY CARD

ON TACHOMETERS
CIRCLE 49 ON INQUIRY CARD

NEW NEW

MULTIMEGAWATT SWITCHES

for radar applications

AMCI
Type 1038-HV
for 6⅛" lines
Type 1136-HV
for 3⅛" lines

For use in Rigid Coaxial Transmission-Line Systems at VHF and UHF

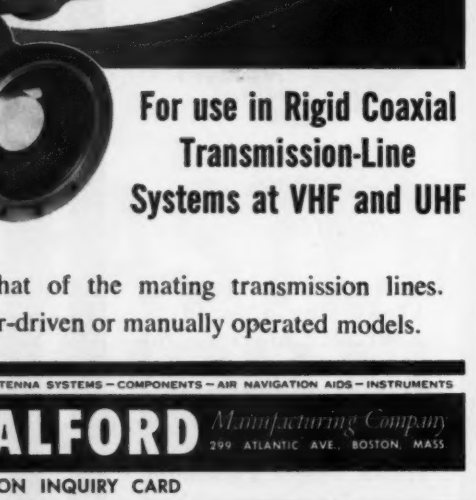
CW rating is approximately that of the mating transmission lines. Switches available in either motor-driven or manually operated models.

Write for complete information on AMCI Coaxial Switches

AMCI ANTENNA SYSTEMS – COMPONENTS – AIR NAVIGATION AIDS – INSTRUMENTS
ALFORD Manufacturing Company
299 ATLANTIC AVE., BOSTON, MASS

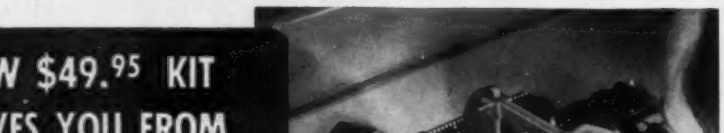
CIRCLE 58 ON INQUIRY CARD

NEW $49.95 KIT MOVES YOU FROM SCHEMATIC TO CIRCUIT *FAST & RELIABLY!*



Here's an all-in-one tool for prototype and small production runs that makes it simple to organize and mount circuitry in compact, planes. It quickly swages Alden terminals, eyelets, brackets and tube sockets, and punches .101" terminal holes in Alden XXP phenolic cards or any 1/16" cold punch card. You can make up circuitry turrets in minutes — complete with terminals, brackets and sockets.

Does ALL these operations:



Makes ALL these parts:

SAVE $10 on kit over individual part prices. **Contains Alden Universal Staking Tool and assortment of prepunched terminal cards, terminals, tube sockets, brackets and eyelets to get started immediately. Order Kit #42 — $49.95 complete.**

ALDEN PRODUCTS CO., 11138 N. Main Street, Brockton, Mass.

CIRCLE 59 ON INQUIRY CARD

MECHANICAL COMPONENTS

Geneva Drives

Standard Geneva Drives have 3 to 24 indexing stations for shaft center distances from 3" to 6" in ¼" increments. Special center distances are also available. Steel wheels are furnished with Meehanite driving wheels and the new drives come in a wide variety of hub and bore diameters. Precise design insures performance, accurate indexing, positive locking, and smooth, trouble-free operation. Genevamatic Engineering Corp., Tampa, Florida.

Circle No. 147 on Inquiry Card

Cable Connector Backshells

Backshells give cable connection extra reliability by keeping cable strain from connector soldering pots and provide additional terminating room at the cable connector. Maximum cable strip-back is increased to give inches with positive clamping action maintained. For further reliability they may be used as potting enclosures; their split-shell design allows installation after wiring of the connector and permits easy removal for inspection of cable/connector assembly. Glenair, Inc., Glendale, Cal.

Circle No. 200 on Inquiry Card

ARE YOU STILL LOOKING FOR A CHIEF DESIGN ENGINEER?

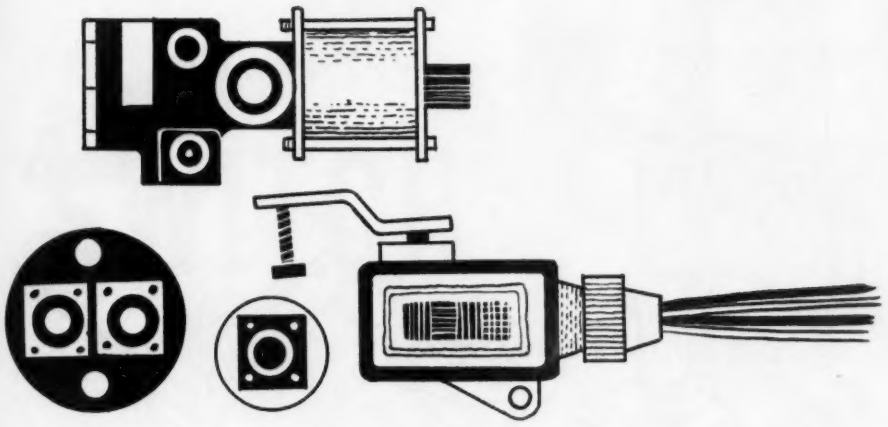
I'm an M. E. who has developed and designed automatic machinery for the production of electron tubes, crystal diodes, whisker leads, wire wound resistors and other electronic and electromechanical components.

In addition, I've designed ovens, honeycomb core machines, machine tools, textile machinery, materials, and chemical processing equipment.

Background includes Harvard Engineering degree and graduate courses in mechanics, materials, electronics, and solid state Physics. Currently employed in the West Coast area.

If you'd like to see a copy of my resume, just drop a note to:

Box 100
ELECTROMECHANICAL DESIGN
1357 Washington Street
West Newton 65, Mass.



Electromechanical Switches Part 3

Coaxial Switches

Coaxial switches are used in radio frequency applications where switching of coaxial cables is required. Frequently a switch is combined with an actuating coil and armature mechanism to provide relay action. The most common applications are in antenna switching, from one antenna to another, or from a dummy load to an antenna. The coaxial switch is used to transfer the antenna from receiver to transmitter in commercial mobile radio applications, commercial airline communications, and all forms of military radio communications for ground, shipboard and aircraft equipments. Crossover (transfer) switches are frequently used to alternate standby equipment, sometimes to a separate antenna, sometimes to a dummy load. Coaxial switches are frequently used in the preliminary stage of transmitter or receiver applications. For instance, a multiple bank of coaxial switches can be used to select frequency multipliers, etc. Many other applications exist as evidenced by the diversity of types, including multi-pole, multi-position, and crossover variety.

The power handling capacity of coaxial switches is determined by the voltage breakdown limits with special regard for transient surges, and the steady state ohmic losses due to flow of RF current. Coaxial switches are designed to work with specific RF connectors.

The three facets of design criteria today on coaxial switches are:

- reliability: 10^6 cycles of life under extreme environmental conditions
- increased frequency range: to 6000 mc, and higher; the broader the band, the more versatile the switch, with a consequent simplification in stocking.
- reduced cross-talk: whereas switches were suitable having cross-talk down by 30db at 2000 mc in the past, new design improvements have been aiming at 80 to 100db.

For military applications and many commercial applications MIL-S-3928, Coaxial, RF Transmission Line Switches provides a convenient reference. MIL-G-5272A is often referenced for environmental purposes. Because application of these devices as well as most other microwave components was primarily military, a good deal of standardization developed which extended to the commercial areas. Refer to "Armed Services Index of R-F Transmission Lines and Fittings (49-2)" for a listing of military approved coaxial switches, and manufacturers.

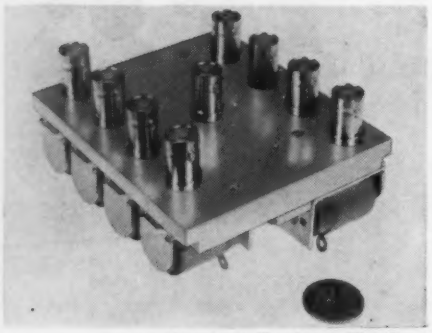
Because of the importance of dielectric characteristics, protection from humidity is important. Hermetic sealing may call for the use of materials having poor dielectric constants and high losses at high frequency. Size, weight, simplicity and reliability requirements further complicate sealing.

SELECTION FACTORS

Factors affecting the selection of coaxial switches are essentially the same as those affecting the selection of more conventional switch types with the exception that microwave considerations such as frequency range, VSWR insertion loss, and cross-talk must be specified. Because of the more cumbersome geometry of coaxial cable in comparison with ordinary low frequency lead wire, as well as the structural characteristics of microwave equipment dictated by performance requirements, coaxial switches are bulky and less susceptible to the wide range of design variations which characterize more conventional switches. Fortunately, microwave applications of coaxial switches are not nearly as varied (circuit-wise) as are conventional switch applications, making it unnecessary to have intricate arrangements such as 12-pole, 4-position, for example. Where application requirements may occasionally demand an exceptionally complicated switching sequence, it is usually possible to combine several standard coaxial switches in an appropriately phased assembly. However, specials are available when necessary. Many manufacturers offer a range of modifications readily available to suit specialized requirements, Fig. 1.

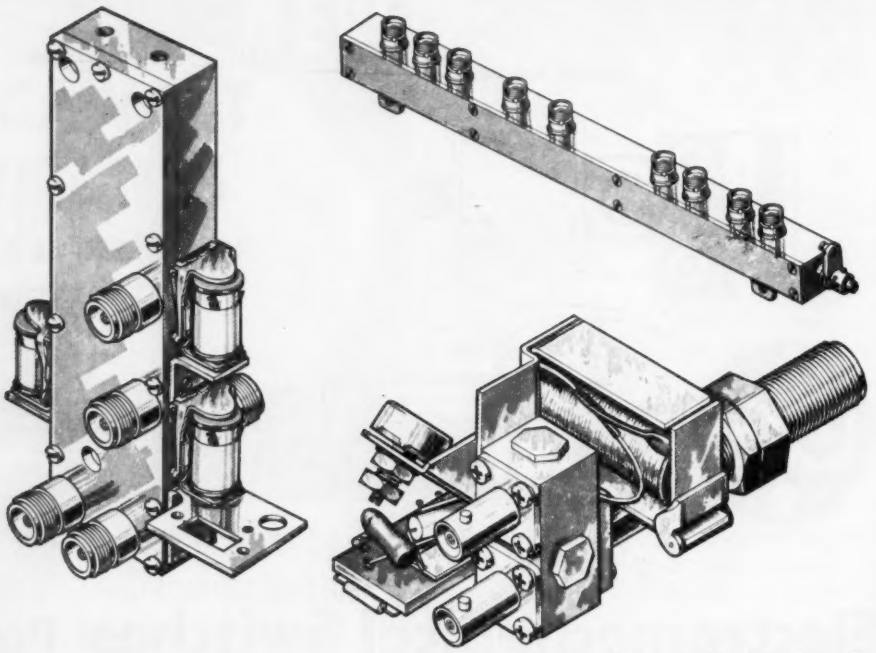
Along with the pure switching function, specialized coaxial switches are available to perform additional functions normally required in conventional switch work and of necessity extending to the micro-wave range. These functions include relay coil switching where remote or automatic operation is required, chopping, and switching for time-sharing or measurement application. Examples of devices for these functions are described below.

COMPONENTS DIGEST



Courtesy Danbury Knudsen

4-position switch with BNC connectors.



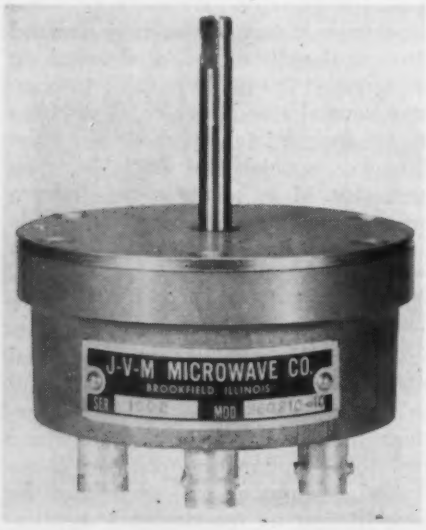
Courtesy Automatic Metal Products Co.

Fig. 1—Some special coaxial switch configurations.

COMMERCIAL COAXIAL SWITCHES

The points involved in the selection of coaxial switches, as well as the permissible design variations are best illustrated by specific examples. Consider the coaxial relay and switch line provided by Automatic Metal Products Corp. This company recommends a selection procedure as follows:

- The basic switch series is selected to meet circuit switching configuration and space requirements. Available space must be related to the geometry of available switch types. The appearance of a number of commercially available coaxial switches is illustrated elsewhere in this Digest.
- The power rating and connector series are determined, the former of course, from circuit requirements, and the latter from among the wide variety of available connectors in accordance with procedures described



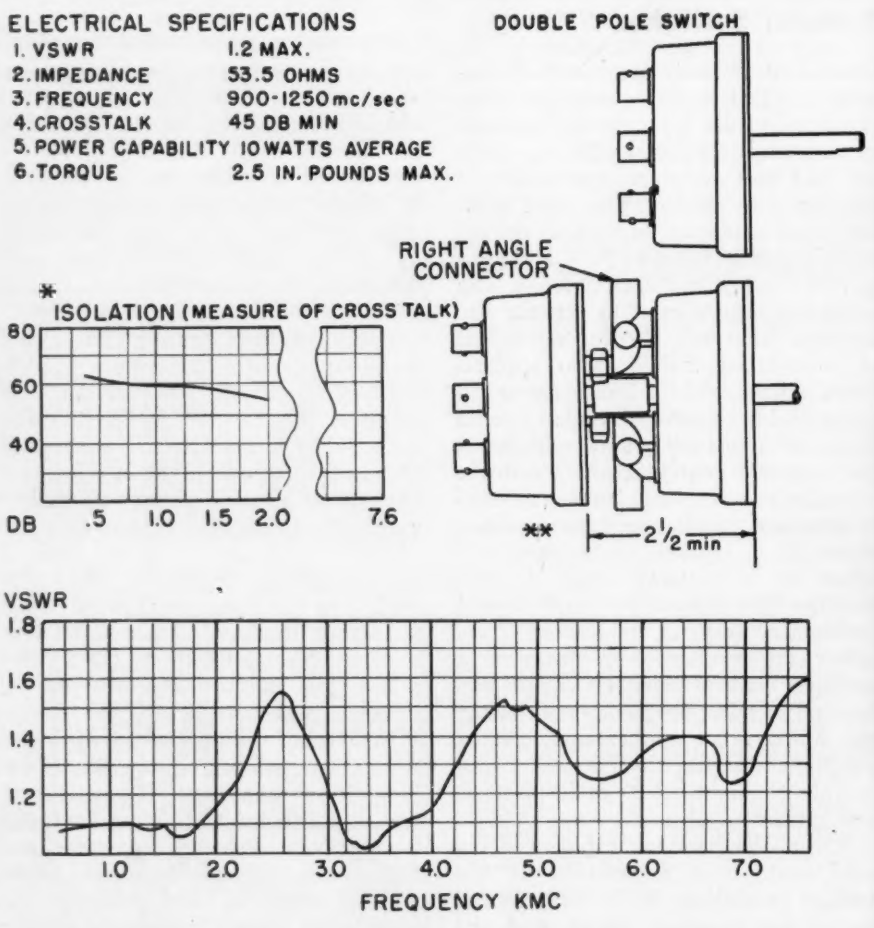

ELECTRICAL SPECIFICATIONS
1. VSWR 1.2 MAX.
2. IMPEDANCE 53.5 OHMS
3. FREQUENCY 900-1250 mc/sec
4. CROSSTALK 45 DB MIN
5. POWER CAPABILITY 10 WATTS AVERAGE
6. TORQUE 2.5 IN. POUNDS MAX.
DOUBLE POLE SWITCH
RIGHT ANGLE CONNECTOR
* ISOLATION (MEASURE OF CROSS TALK)
80
60
40
DB .5 1.0 1.5 2.0 7.6
** 2 1/2 min
VSWR
1.8
1.6
1.4
1.2
1.0 2.0 3.0 4.0 5.0 6.0 7.0
FREQUENCY KMC
* NOTE: ABOVE 2000 mc ISOLATION IS AT LEAST 40DB BETWEEN ADJACENT CHANNELS. EXACT DATA IS NOT AVAILABLE AT PRESENT.
** OPTIONAL METHOD OF CONNECTING SWITCHES IN TANDEM. (BNC OR TNC CONNECTORS ONLY. SOLID OR FLEXIBLE COUPLINGS)

Fig. 3—Performance characteristics of a coaxial switch. Figure also shows physical appearance of these switches, and provision for cascading.

NEW sub-sub- miniature SWITCH

actual size

with amazing performance characteristics for miniaturized controls

Carries 7½ amp @ 125/250 VAC . . . U.L. approved. Handles loads 50% greater than any switch in its size class. Perfect for office machines, etc.

Withstands 50 G Shock . . . Rugged enough for missile and aircraft applications.

Only .003" Movement Differential . . . Sensitive enough for the most delicate pressure switch controls.

No Measurable Dead-Break . . . Dependable switching even at very slow actuation speeds.

Only 2-Microsecond Switching Speed . . . Fast enough for high-speed computers and military controls.

Designed for Reliability . . . The only switch this small having only TWO moving parts.

Exclusive One-Hole Mounting . . . For faster, easier assembly and precision alignment. When stacking units, molded stud on case locks into matching hole on next unit. Single mounting screw passes through all units to form rigid gang. No second mounting hole tolerances to cause uneven alignment in critical assemblies. You save hardware costs, assembly time.

T-SERIES
SWITCH SPECIFICATIONS

Silver cadmium inlay terminal contacts.

Silver rivet moving contact on beryllium copper leaf.

Solder lug terminals standard; spade type optional.

Cut-away photo actual size.

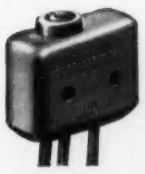
S.P.D.T.	
Weight	1.6 grams (.057 oz.)
Operating Force	200 grams (7.05 oz.) max.
Pretravel	.010" approx.
Overtravel	.005 min.
Movement Diff.	.003 max.
Release Force	30 grams (1.06 oz.)
Contact Pressure	50 grams (1.56 oz.)
Contact Gap	.020 approx.
Mechanical Life	150,000 cycles, min.
Ambient Temp.	−65° to +250° F (350° avail.)
Electrical Rating	7½ amps, 125/250 VAC 6 amps, 30 VDC, resistive 3 amps, 30 VDC, inductive

Write for full data on T-Series Switches.

ELECTROSNAP CORPORATION
SWITCH DIVISION
4260 West Lake Street • Chicago 24, Ill.
Telephone VAn Buren 6-3100 • TWX CG-1400

actual size
E4-100 series
SPDT

sub-miniature
L.W.H. 2⅜₂" x .250" x 2¾₆₄"
Elec. 5 amps @ 125/250 V.A.C.
Rating: 4 amps Res. @ 30 V.D.C.
2.5 amps Ind. @ 30 V.D.C.
Operating Force 150 grams max.
Amb. Temp. −65° to +250°F.
E4-107 −65° to +350°F.
Variety of termination and operating characteristics. Military and U.L. models.


actual size
EF-100 series
SPDT

environment free
L.W.H. ⅞" x 1¹⁄₃₂" x 1⁹⁄₃₂"
Elec. 5 amps @ 125/250 V.A.C.
Rating: 4 amps Res. @ 30 V.D.C.
2.5 amps Ind. @ 30 V.D.C.
Operating Force 5 to 17 oz.
Amb. Temp. −65° to +180°F.
EF-105 −65° to +350°F.
Enclosed basic switch conforms to MIL-S-6743, with entire unit meeting MIL-E-5272A.

actual size

miniature
SPDT
L.W.H. 1³⁄₃₂" x 1³⁄₃₂" x ⅝"
Elec. 10 amps @ 125/250 V.A.C.
Rating: 60 cycles
10 amps Res. @ 28 V.D.C.
6 amps. Ind. @ 28 V.D.C.
Operating Force 7 to 12 oz.
Amb. Temp. −100° to +350°F.
Screw or solder terminals. Military and U.L. models.

CIRCLE 51 ON INQUIRY CARD

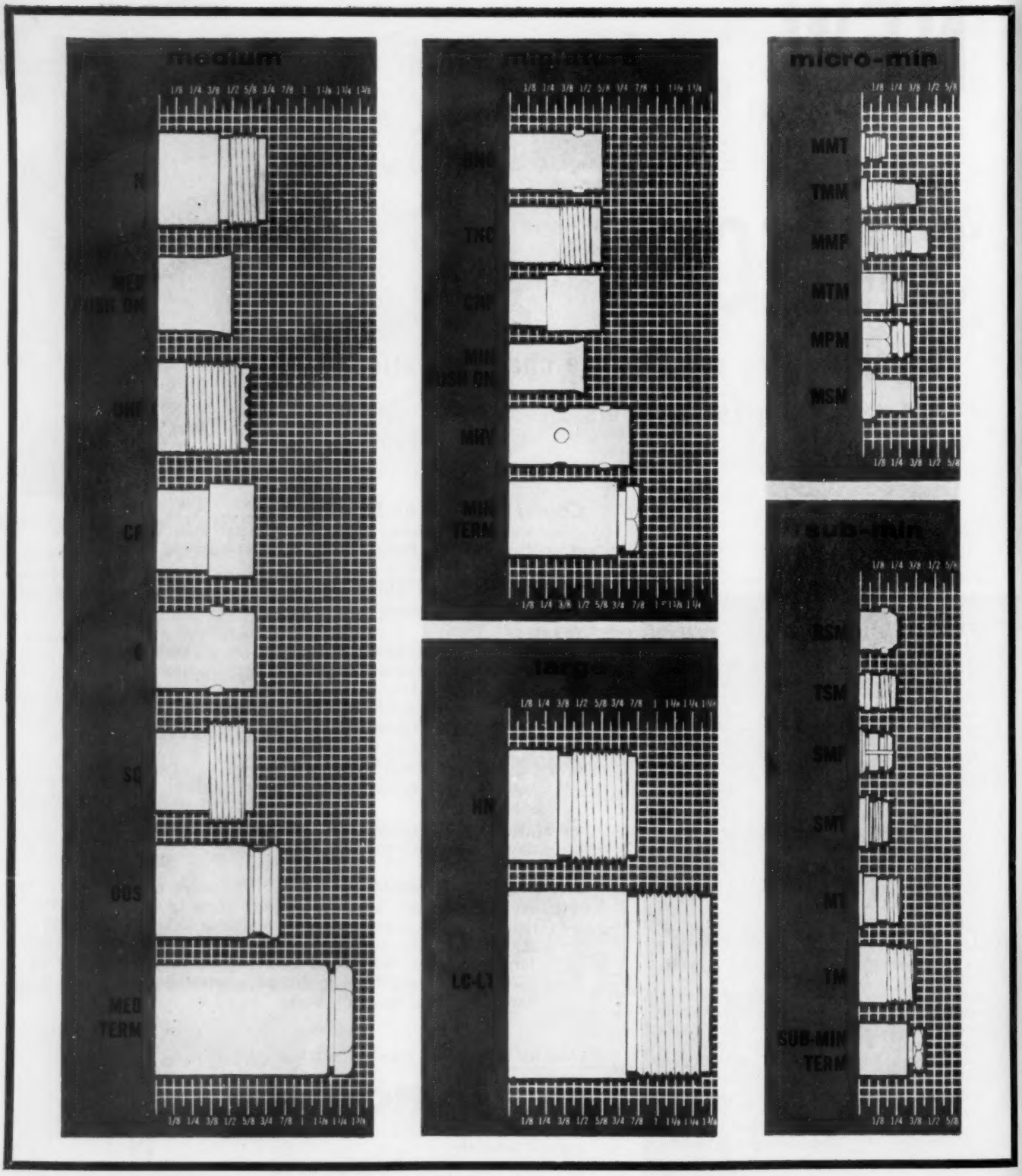


Fig. 2—Connector Selection, Approximate Configurations.

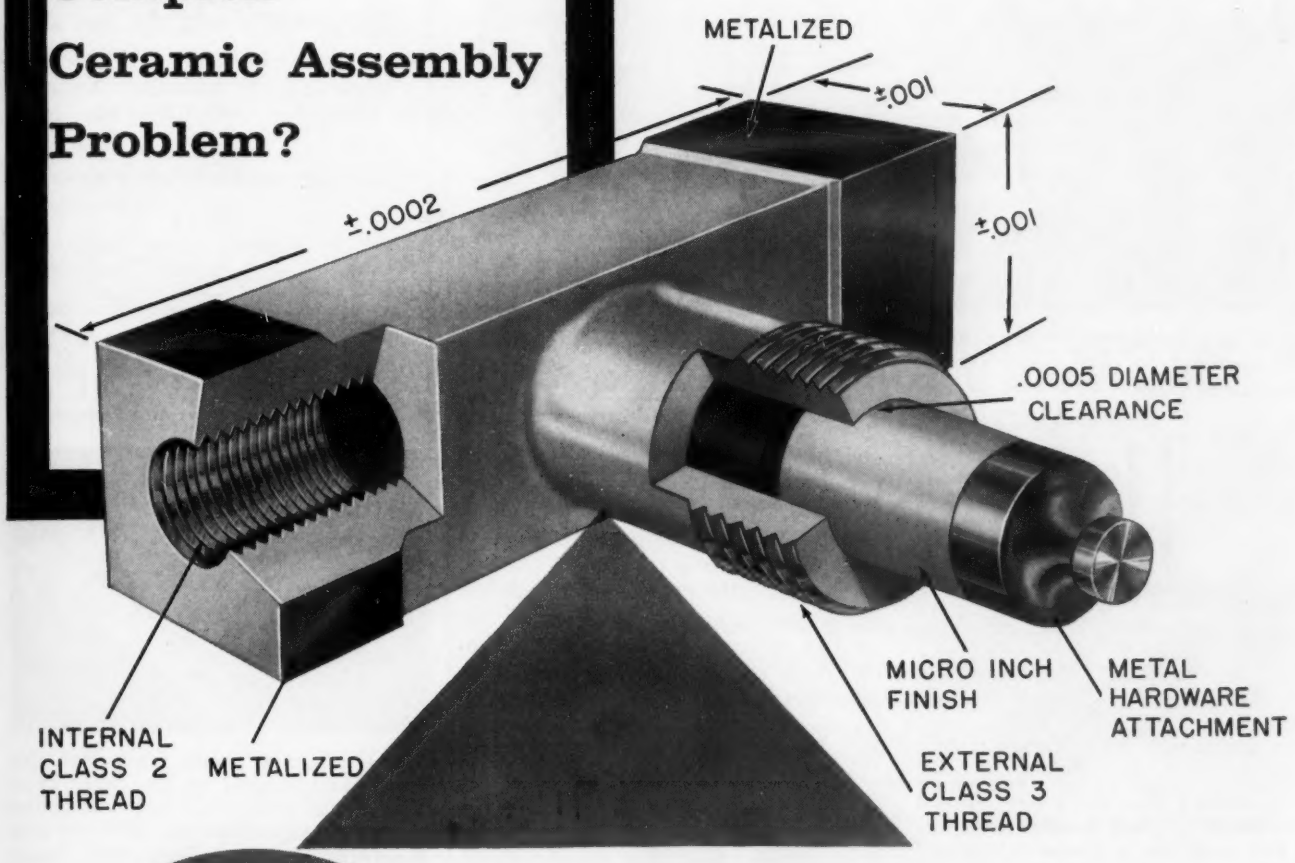
in Component Digest 6, Part I and II on electrical connectors. For convenience, a connector selection chart compiled by Automatic Metal Products Corp. is reproduced in Fig. 2. Coaxial switches are generally designed to be fitted with most, or all, of these currently available connectors, and are available in compatible sizes.

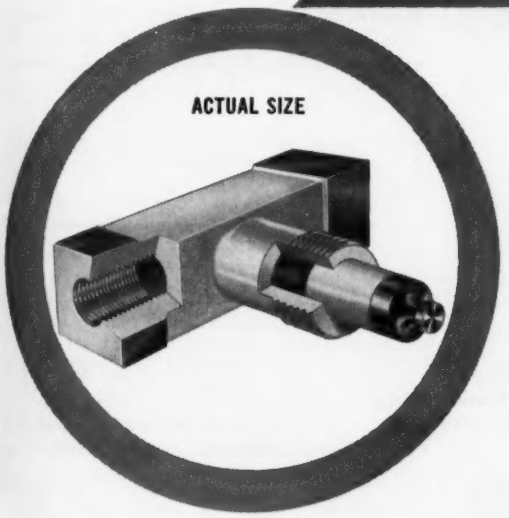
- When ordering a coaxial switch, specify: switch series, connector series, circuitry, physical location of connectors, maximum frequency and power, and maximum permitted insertion loss.
- If remote operation is required, specify coil voltage and resistance. Standard coil ratings, such as 28 volts dc, 110 or 220 volts ac are usually available.

Additional selection factors include. low cost; small size; reliability; low crosstalk, terminating the unused connections with either a short, or a matching resistor; fast operation; long life; low wattage operating coils; suitable temperature range; moisture; moisture and salt spray resistance; vibration and shock resistance; adequate contact capacity for the power ratings. Figure 3 illustrates some of the above selection factors in a specification by J.V.M. Microwave Co. Danbury-Knudsen lists a variety of modifications that may be applied to their standard types, reproduced in Table I as a selection aid.

Alford Mfg. Co. emphasizes relia-

Complex Ceramic Assembly Problem?





Centralab solves them daily

The pictured unit shows how CENTRALAB can control the manufacturing of precision ceramic-to-metal assemblies to extremely close tolerances, no matter how complex the shape, how intricate the machining. Let CENTRALAB design and production engineering help you take full advantage of the superior electrical and physical properties of High Alumina and Steatite ceramics.

You can achieve improved performance *and* eliminate production assembly problems by utilizing CENTRALAB's know-how in the specialized techniques of close tolerance ceramic-to-metal fabrication. CENTRALAB can handle complex, precision assemblies involving machining of ceramics or metals to ±.0002", metalizing of ceramics, cementing, riveting, soldering, plating, and stamping.

For detailed information on how High Alumina and Steatite ceramics can solve your electromechanical problems, write for free copy of CENTRALAB's new Ceramic Design Handbook (Bulletin No. 42-554), or consult Sweet's Product Design File (folio 4a/ce).

Centralab

X-5970

A DIVISION OF GLOBE-UNION INC.
924K E. KEEFE AVE. • MILWAUKEE 1, WISCONSIN
In Canada: 669 Bayview Ave., Toronto 17, Ontario

VARIABLE RESISTORS • SWITCHES • CERAMIC CAPACITORS • PACKAGED ELECTRONIC CIRCUITS • ENGINEERED CERAMICS

CIRCLE 52 ON INQUIRY CARD

COMPONENTS DIGEST

bility as a selection factor for coaxial switches. To insure this quality they use solid silver in their contact assemblies. They also use a flanged type-fitting construction so that any of their units can be incorporated in pressurized circuits for reliable outdoor installations. In one series designed to handle high peak power they round off all edges in the contact area to prevent concentration of electric fields that would result from sharp edges or points. Fig. 4 shows one of Alford's newer switches for 3⅛" rigid coaxial transmission lines.

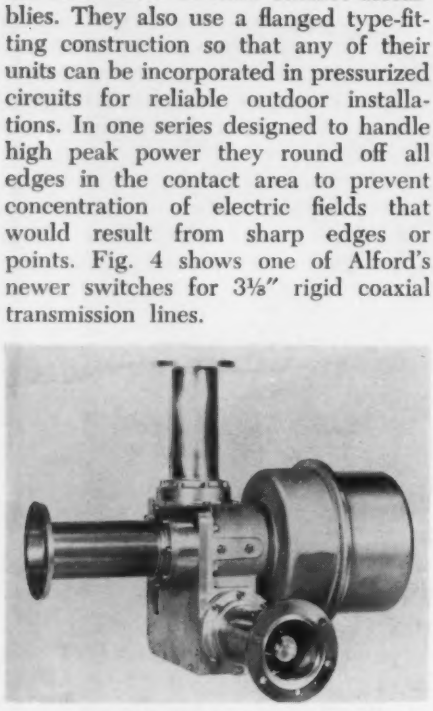
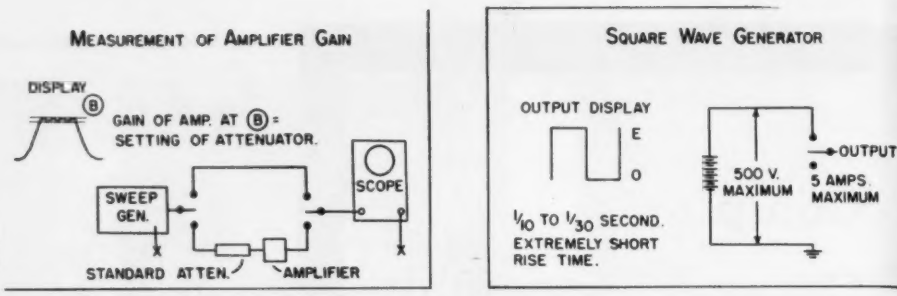


Fig. 4—Alford Mfg. Co.'s new coaxial switch for 3⅛" rigid coaxial transmission line available in motor driven and manually-operated models. It has a frequency range of 0-500 mc with a VSWR under 1.05. Its cw power rating is approximately that of 3⅛" coaxial transmission line, and crossta'k through the unused branch is over 60 db down at 80 mc and over 40 db down at 500 mc.

Jennings Radio Manufacturing Corporation, also emphasizing reliability as a selection factor for coaxial switches, places the contacts in a vacuum to insure their permanent freedom from corrosion or oxidation. Thus the contact resistance remains permanently low and there is no change in



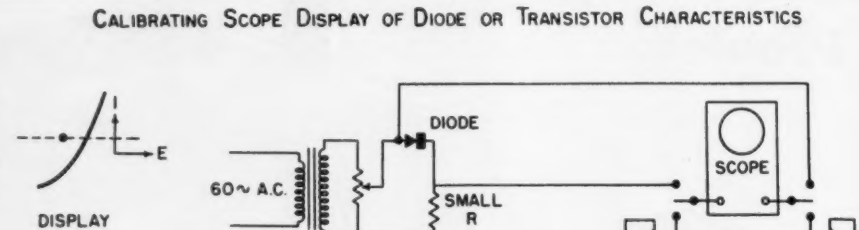


Fig. 11—Application diagrams of coaxial switch for measurement and comparison

electrical characteristics during long periods of storage or use. They point out also that because there is little arcing during current interruption in a vacuum, there is no contact damage if the relay is accidentally switched hot. Other important specifications, according to Jennings are ability to handle high power and especially high pulse power in a minimum space, fast transfer time and high frequency operation. They are currently developing

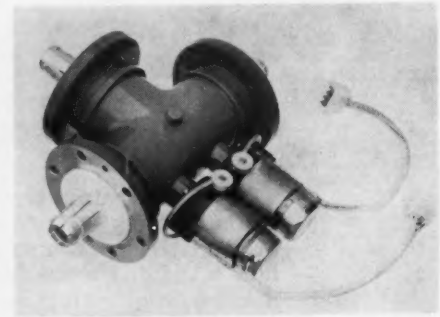


Fig. 5—Jennings Radio 50 ohm single thow vacuum relay for remotely switching 3⅛" coaxial line at frequencies up to 600 mc. Power rating is 3 mw peak and 200 kw average at 500mc. Insertion loss is 0.05 db max. VSWR is from 1.03 to 1.09 and cross ta'k is 37.5 db down at 600 mc.

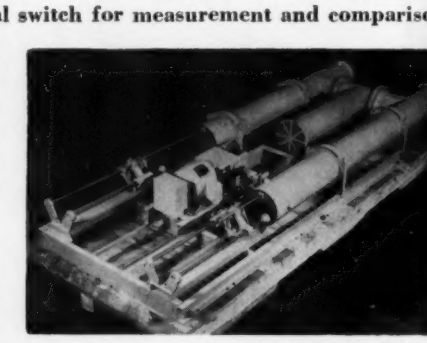
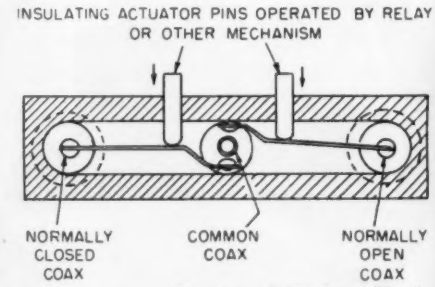
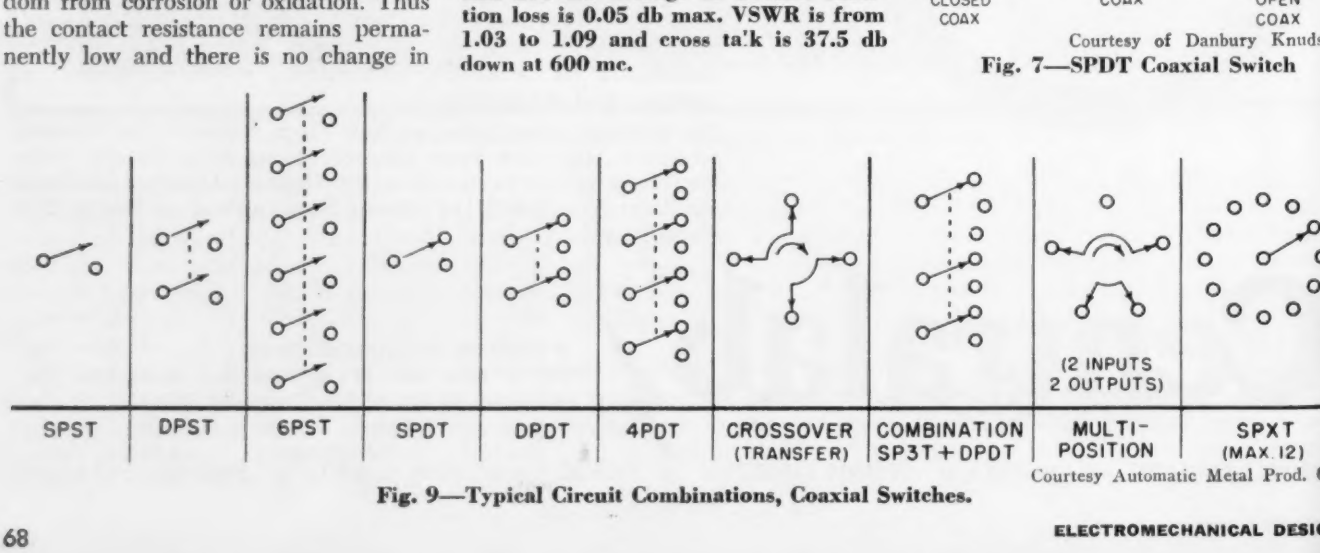


Fig. 6—Coaxial switch for 9 inch line size, manufactured by Dielectric Products Engineering Co., Inc. Center frequency is approximately 200 mc with bandwith plus or minus 10%. Insertion loss is 0.05 db, VSWR is 1.1 to 1.0 and crosstalk is over 35 db down.



Courtesy of Danbury Knudsen

Fig. 7—SPDT Coaxial Switch



Courtesy Automatic Metal Prod. Co.

Fig. 9—Typical Circuit Combinations, Coaxial Switches.

TABLE I

Modifications That May Be Applied To Standard Types

An open type solder terminal in place of a connector.

Various combinations of connectors on the same switch.

Auxiliary contacts. One input standard shorting contacts, and the other input non-shorting.

One input, resistor terminated and the other input, shorting or non-shorting.

DPDT operation for manual operation with a single toggle stem.

DPDT remote operation requires the use of two actuating coils, but the two switches can be mounted on one plate.

Pressurized thru mounting panel connectors.

Metal covers over the coil assembly except when supplied wth resistor terminations or auxiliary contacts.

Standard coaxial connectors assembled to attached cables in specified lengths.

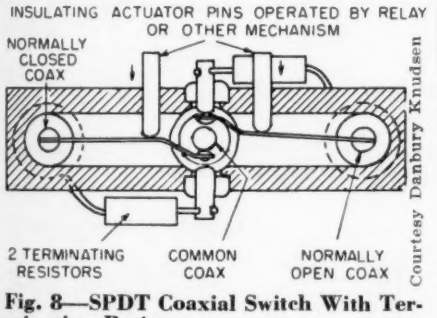


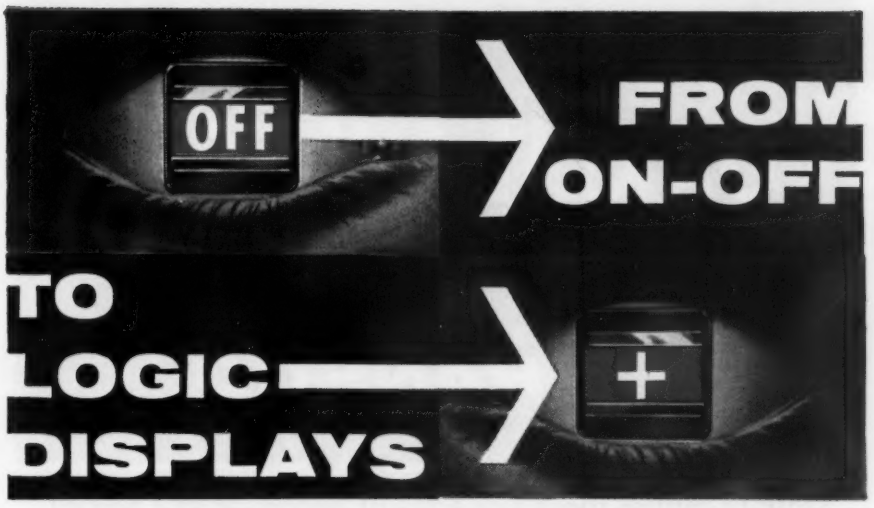
Fig. 8—SPDT Coaxial Switch With Terminating Resistor

vacuum coaxial switches employing high speed actuators with operate times of 10 milliseconds. They are also working on a 1⅝" vacuum unit.

Dielectric Products Engineering Co. of Raymond, Maine, makes coaxial switches for line sizes ranging from ⅞" to 9 inches. Fig. 6 illustrates their 50-ohm, single pole, double throw unit for 9 inch line size.

CONSTRUCTION FEATURES

Although many different switching mechanisms are in common use, such as leaf spring switching members, toggle devices, and rotary actuators (see Components Digest 8, Part I and II on switches), the basic switching function is illustrated in the typical designs of Figs. 7 and 8 showing SPDT coaxial devices. Fig. 7 shows an ar-

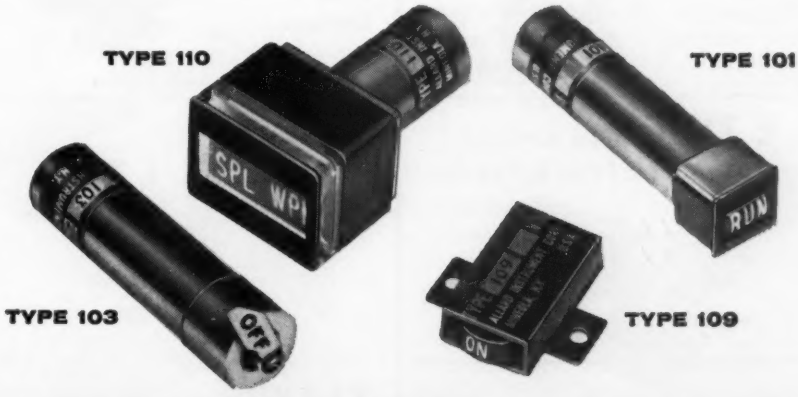


ALLARD ELECTROMAGNETIC INDICATORS GIVE YOU POSITIVE SIGNALING IN MITE-SIZE PACKAGES

Designed expressly for compact instruments and control panels, Allard miniature indicators meet the most critical requirements for small size, low power drain, positive performance in extreme environments.

Unlike lamp signals they are not subject to burnout, provide high readability even in strong incident light. What's more—Allard indicators offer unparalleled application flexibility, permit complex indications without the need for relays or grouping of multiple units.

Typical of the wide range of Allard signals available for demanding airborne or ground service are those shown here. All can be supplied to meet most specifications for display, operating voltage and mounting, in models for either military or industrial applications.



TYPE 101:	TYPE 103:	TYPE 109:	TYPE 110:
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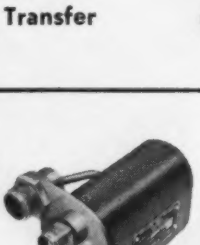
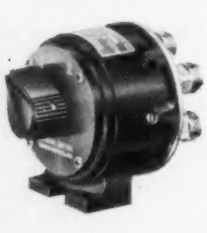


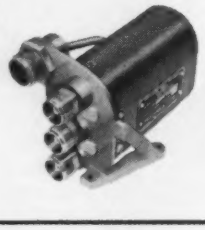
A TYPE Solenoid Actuated SP3T, SP4T

AX TYPE Solenoid Actuated Transfer

M TYPE Manual SPDT to SP6T, DPDT & Transfer



E TYPE Motor Actuated SPDT to SP6T, DPDT & Transfer



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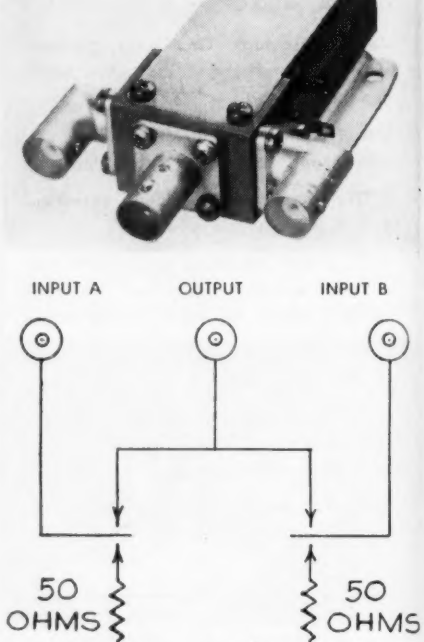

Fig. 10—Schematic diagram and photograph of coaxial chopper.

rangement which may be adapted to either manual or relay operation by adding an appropriate actuating mechanism. The center cable provides the input circuit which is normally connected to the lefthand output cable. Actuating the switch transfers the connection to the right hand connector. The unused circuit is grounded. Fig. 8 illustrates a similar connector in which the open coaxial connectors are terminated in a suitable matching resistor. This grounding of unused circuits greatly improves circuit isolation or cross-talk, an important characteristic in the 5-5000mc range where these switches are normally used.

Contact configuration of course relates directly to the required switching function. Fig. 9 shows typical contact arrangements in a relay actuated coaxial switch, and in a rotary mechanically actuated device.

ADDITIONAL APPLICATIONS

Hand in hand with the use of coaxial switches has gone the development of related switching devices. Jerrold Elec-

tronics describes a high speed electronically controlled coaxial switch used for the simultaneous display of two channels or voltages on an oscilloscope. A principal use is in measurements by the comparison method where it saves time over the use of manually operated coaxial switch. Fig. 10 shows some application circuits.

James Vibrapowr Co. manufacturers a coaxial chopper designed to conduct signals from d-c levels to frequencies in excess of 400 mc, Fig. 11. The chopper can be used in radio direction finding equipment, multiple antenna sampling, continuous signal comparison or test and control equipment.

End of CD8

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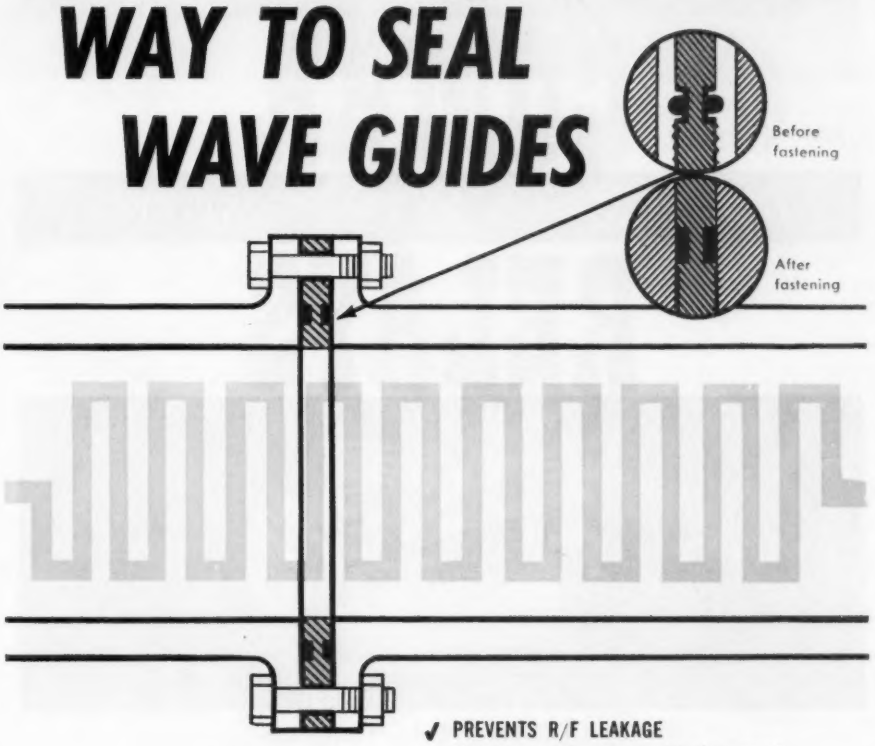

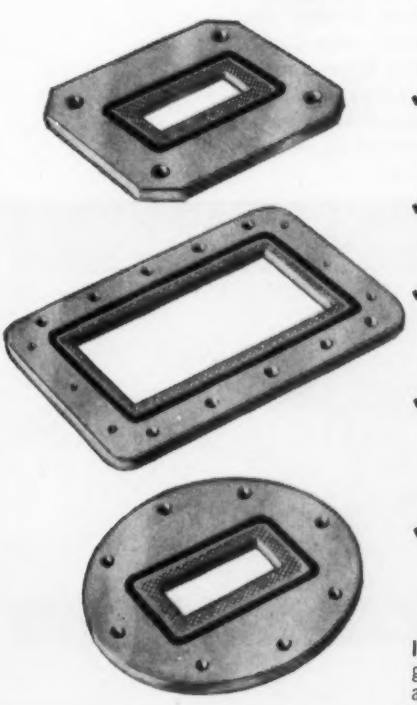

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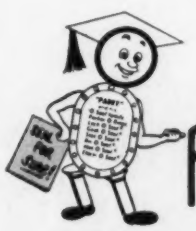

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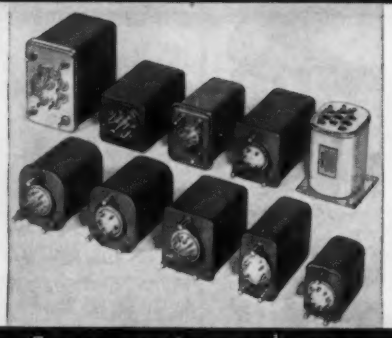

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